Design of Affordable and Efficient Ground-Source Heat Pump Systems

Stephen Kavanaugh, Ph.D., Fellow ASHRAE
University of Alabama and
Energy Information Services
skavanaugh@eng.ua.edu
www.geokiss.com

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About the Instructor

Stephen Kavanaugh, Ph.D., Fellow ASHRAE, is professor emeritus of mechanical engineering at the University of Alabama-Tuscaloosa. He is a past chair of ASHRAE Technical Committee 6.8 Geothermal Energy, and past chair of TC 9.4 Applied Heat Pumps and Heat Recovery. He is also a Fellow of the American Society of Mechanical Engineers.

Kavanaugh is the author of several ASHRAE publications including: *Geothermal Heating and Cooling: Design of Ground-Source Heat Pump Systems* (2014); *HVAC Simplified* (2006); and *Ground Source Heat Pumps: Design of Geothermal Systems for Commercial and Institutional Buildings* (1997). He also received the ASHRAE Technical Achievement Award in 2001.

Since 1993, Kavanaugh has owned Energy Information Services, which operates the GeoKISS website www.geokiss.com. GeoKISS provides accurate information on ground-source (geothermal) heat pumps, enabling designers and installers to develop affordable, long lasting and low energy systems by using “simple and solid piping, equipment and controls.”

Kavanaugh has also been actively involved with Habitat for Humanity for many years. He was chair of the board of directors twice for the Tuscaloosa Affiliate. He has worked on about 50 Habitat homes (including one with a GSHP system), and he was a construction supervisor for five of them. And for most of his life, Kavanaugh lived in homes that were heated and cooled by GSHP systems.

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Learning Objectives

1. Understand GSHP nomenclature, system types, and appropriateness of various options.
2. Become acquainted with equipment options and methods of calculating system performance.
3. Learn the procedures for ground-coupled (closed-loop) heat exchanger and piping design.
4. Become familiar with GSHP system costs and field-measured performance data.
5. Gain knowledge of available ASHRAE resources to improve and expedite GSHP design.

Course Outline

- Session 1: Introduction to Ground-Source Heat Pumps
- Session 2: Equipment for Ground-Source Applications
- Session 3: Applied GCHP Design
- Session 4: Piping and Pumps for Closed-Loop Ground-Source Heat Pumps
- Session 5: GSHP Performance and Installation Cost

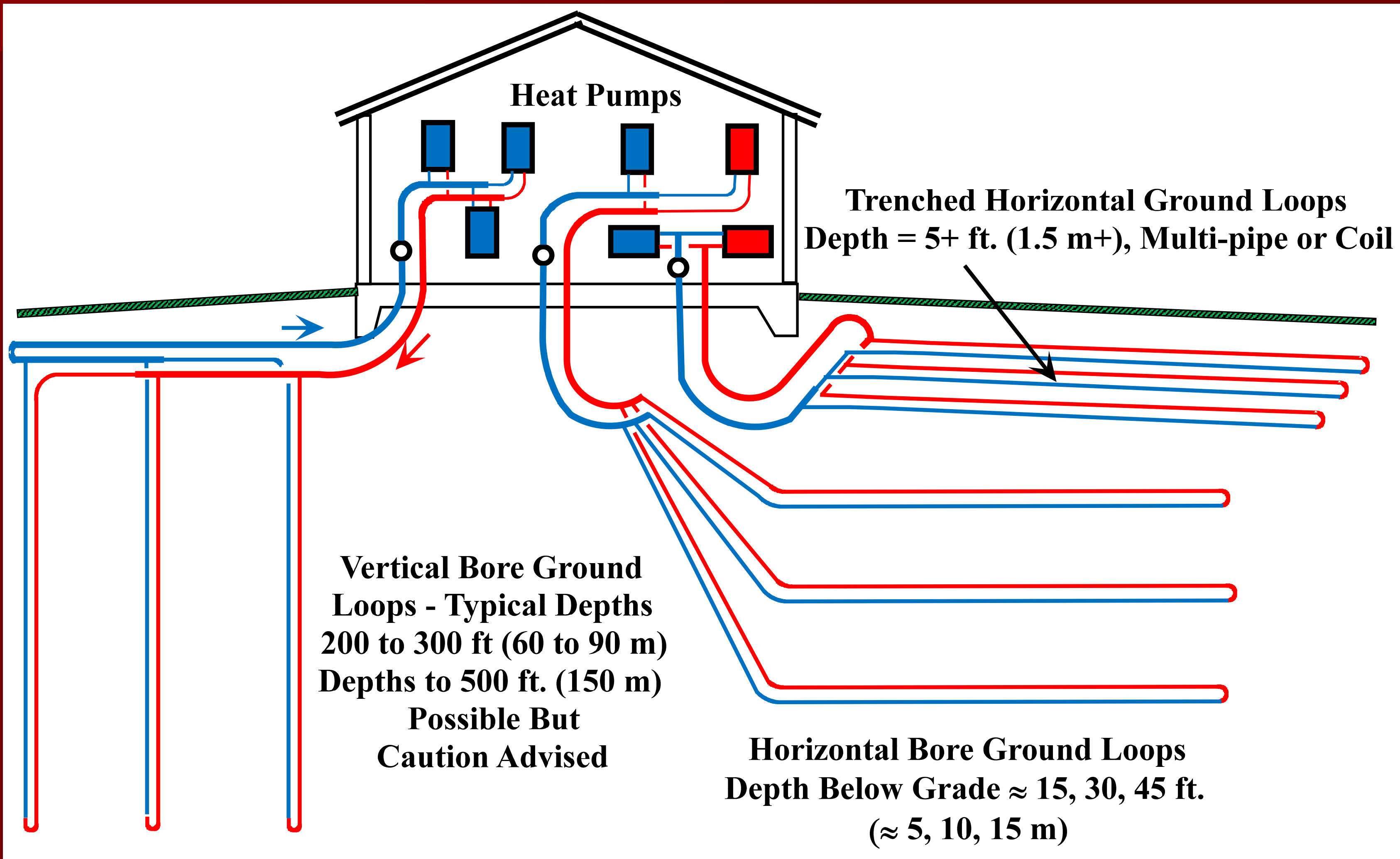
Session 1

INTRODUCTION TO GROUND-SOURCE HEAT PUMPS

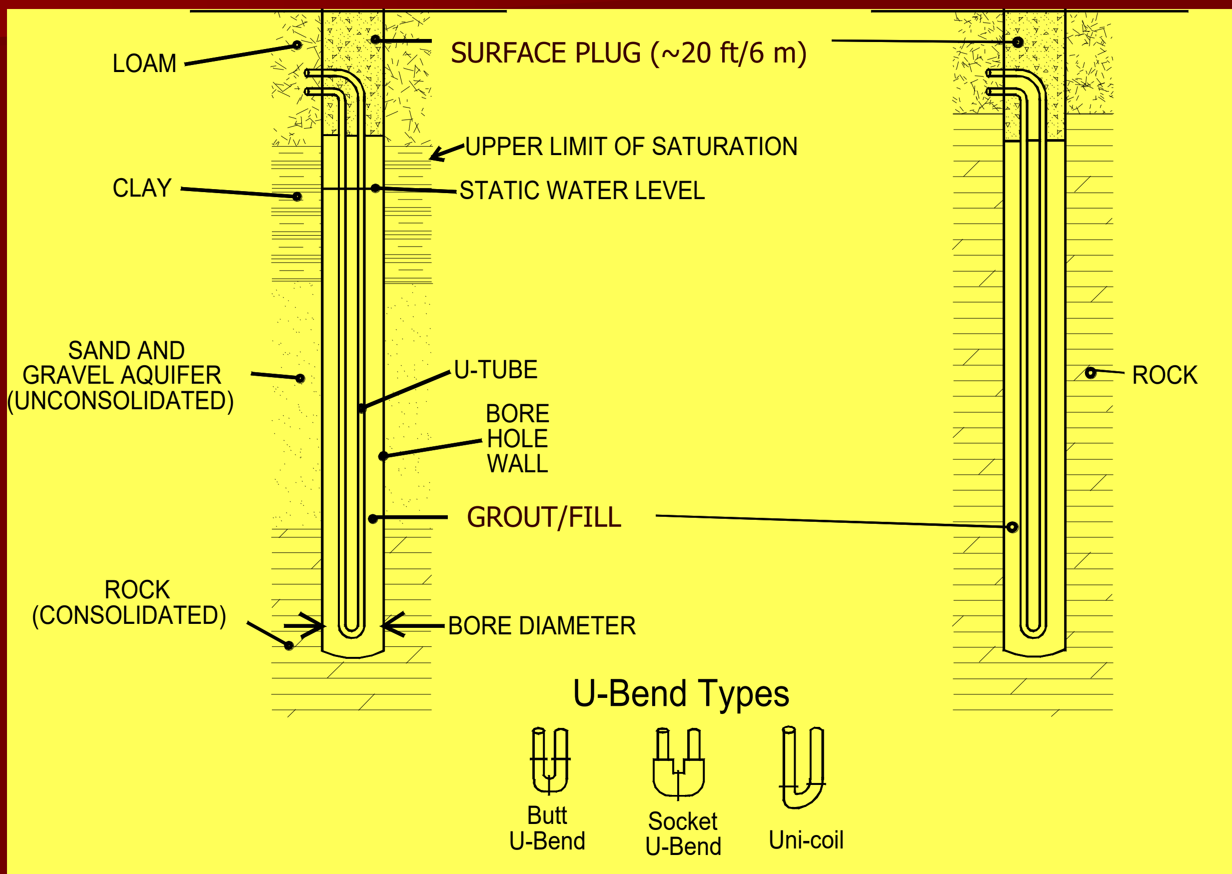
Some References

- 2015 *ASHRAE Handbook—HVAC Applications*, Chapter 34
- *Geothermal Heating and Cooling: Design of Ground Source Heat Pump Systems* (ASHRAE, 2014)
- *ASHRAE Journal* articles, "Long Term Commercial GSHP Performance," Vol. 54, Nos. 6, 7, 9, 10, 12; Vol. 55 Nos. 1 & 2
- www.geokiss.com

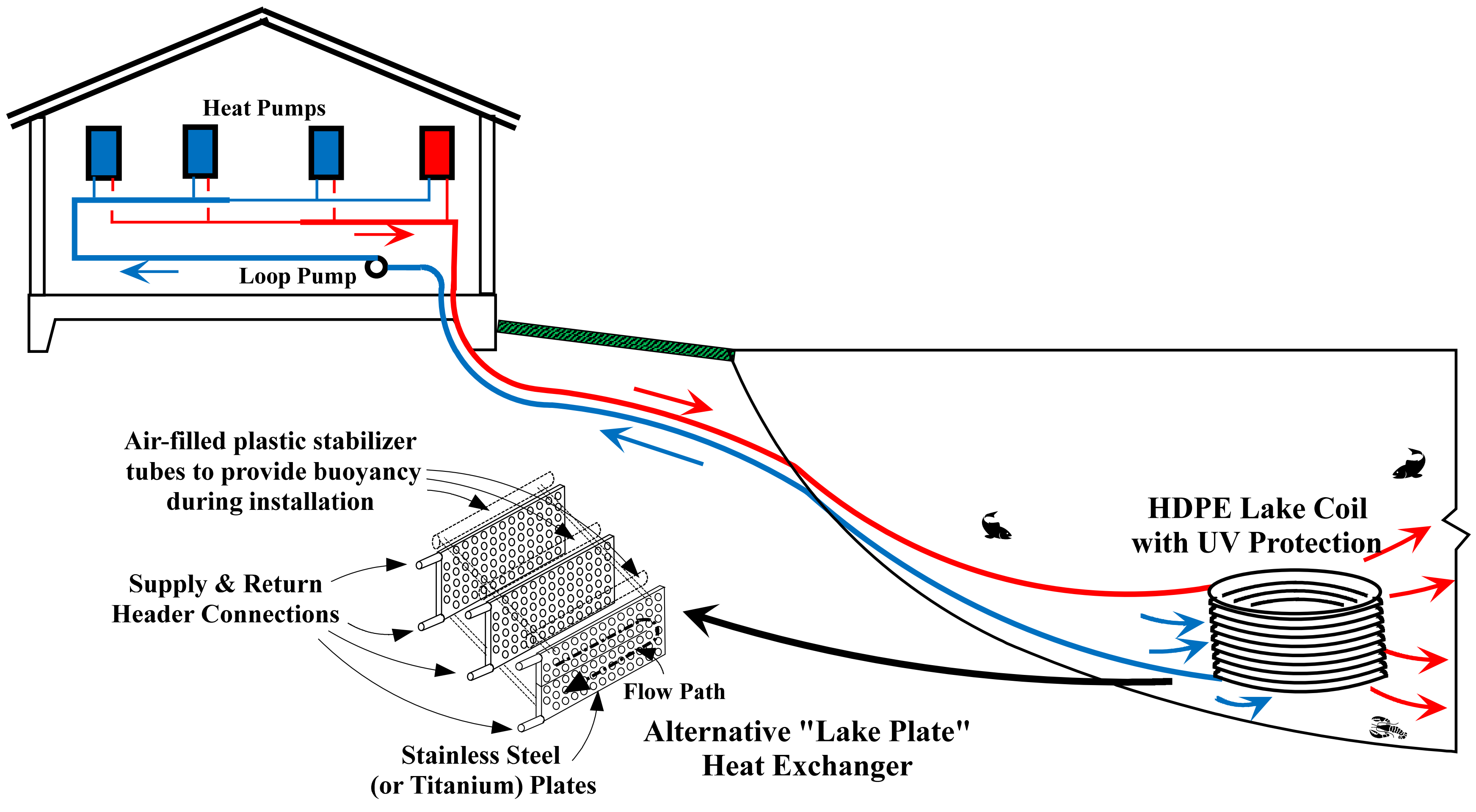
Ground-Coupled Heat Pumps (GCHPs) (a.k.a. Closed-Loop Geothermal) Description and Nomenclature



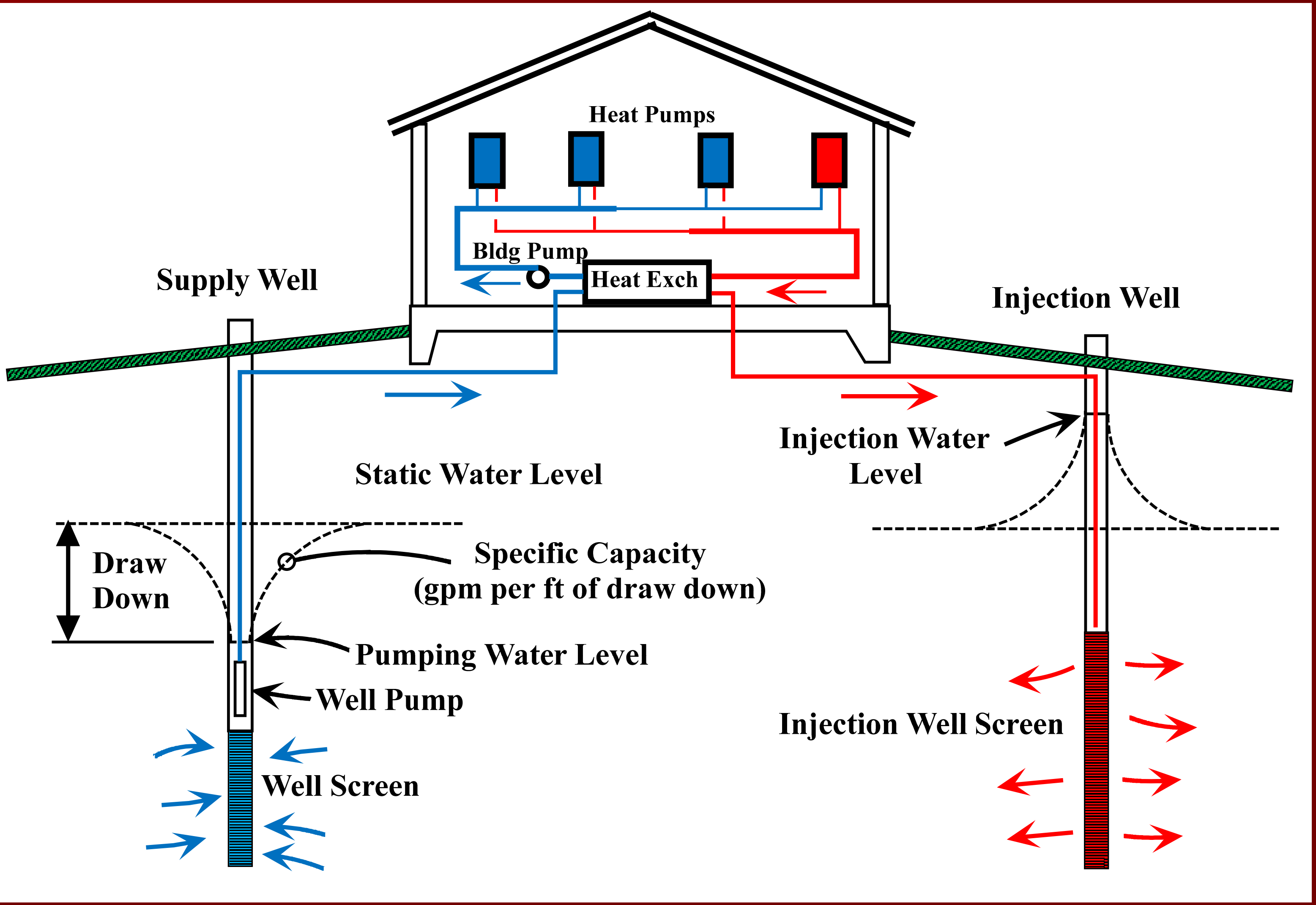
Vertical Ground Heat Exchanger Terms for Two Typical Formations



Surface Water Heat Pumps (SWHPs)
(a.k.a. Pond Loop, Lake Loop, Ocean Loop, Open Loop)
Description and Nomenclature

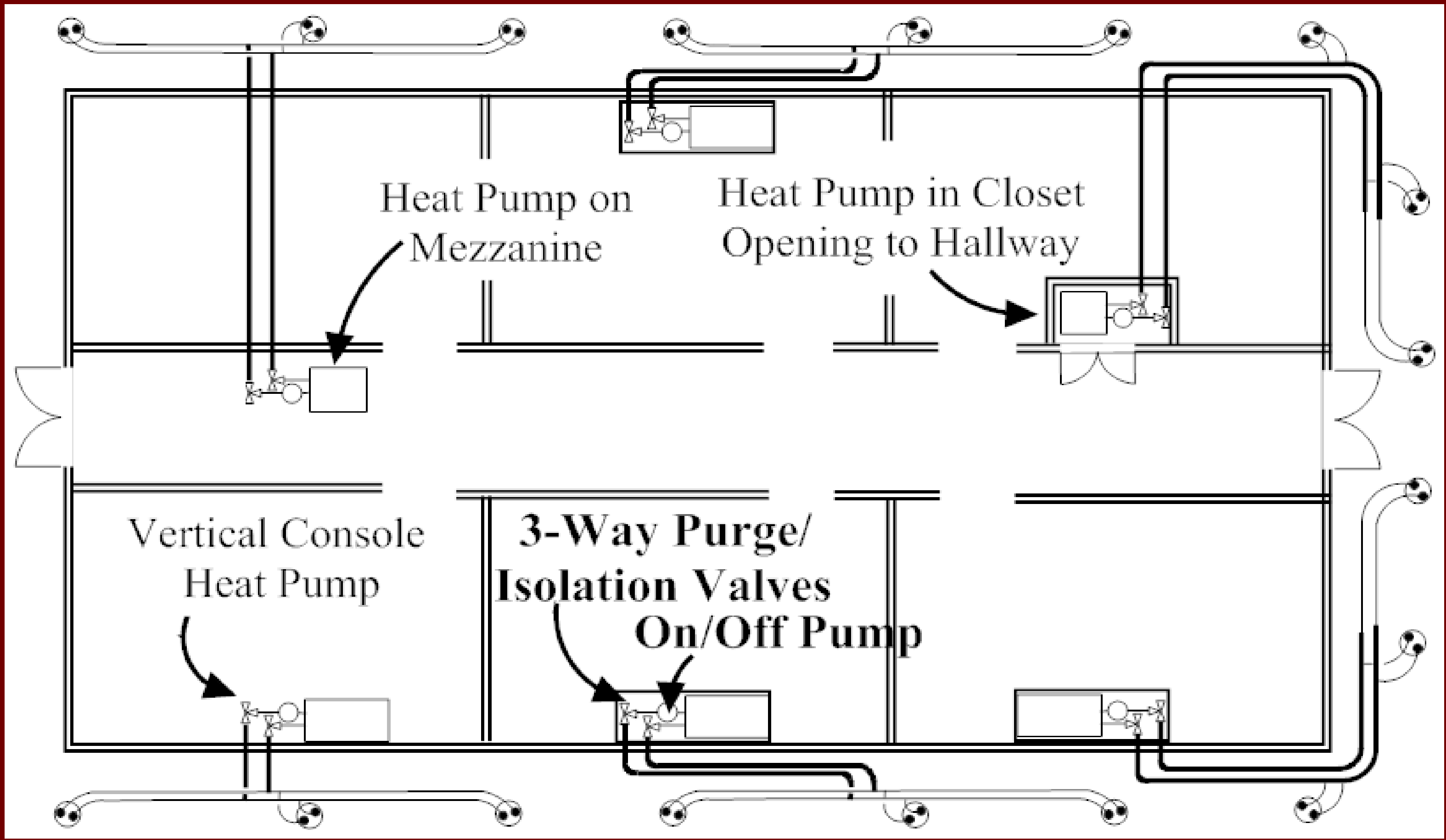


Ground-Water Heat Pumps (GWHPs)
(a.k.a Open-Loop Geothermal)
Description and Nomenclature



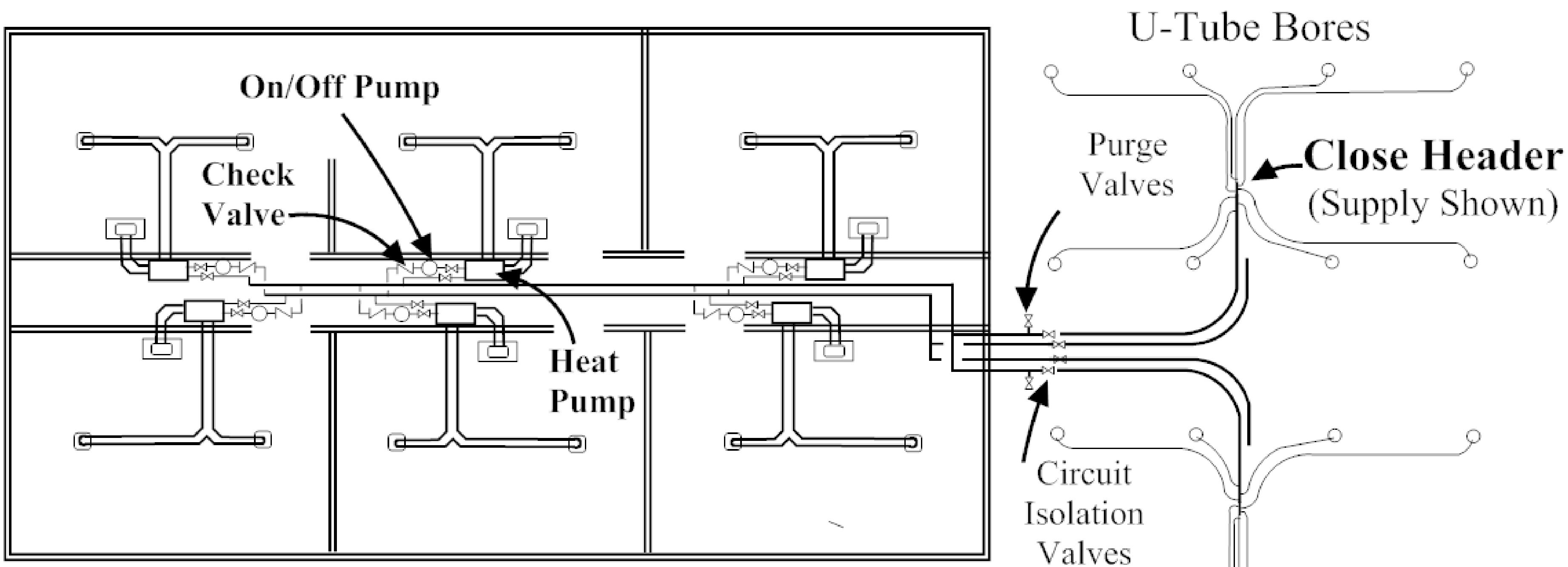
GCHP—Unitary Loop Option

Highest Average Energy Star Rating,
Simple Installation, Control and Maintenance,
Relatively Low Installation Costs,
Best with Low-Rise, Large Footprint Building



GCHP—Common Loop Option

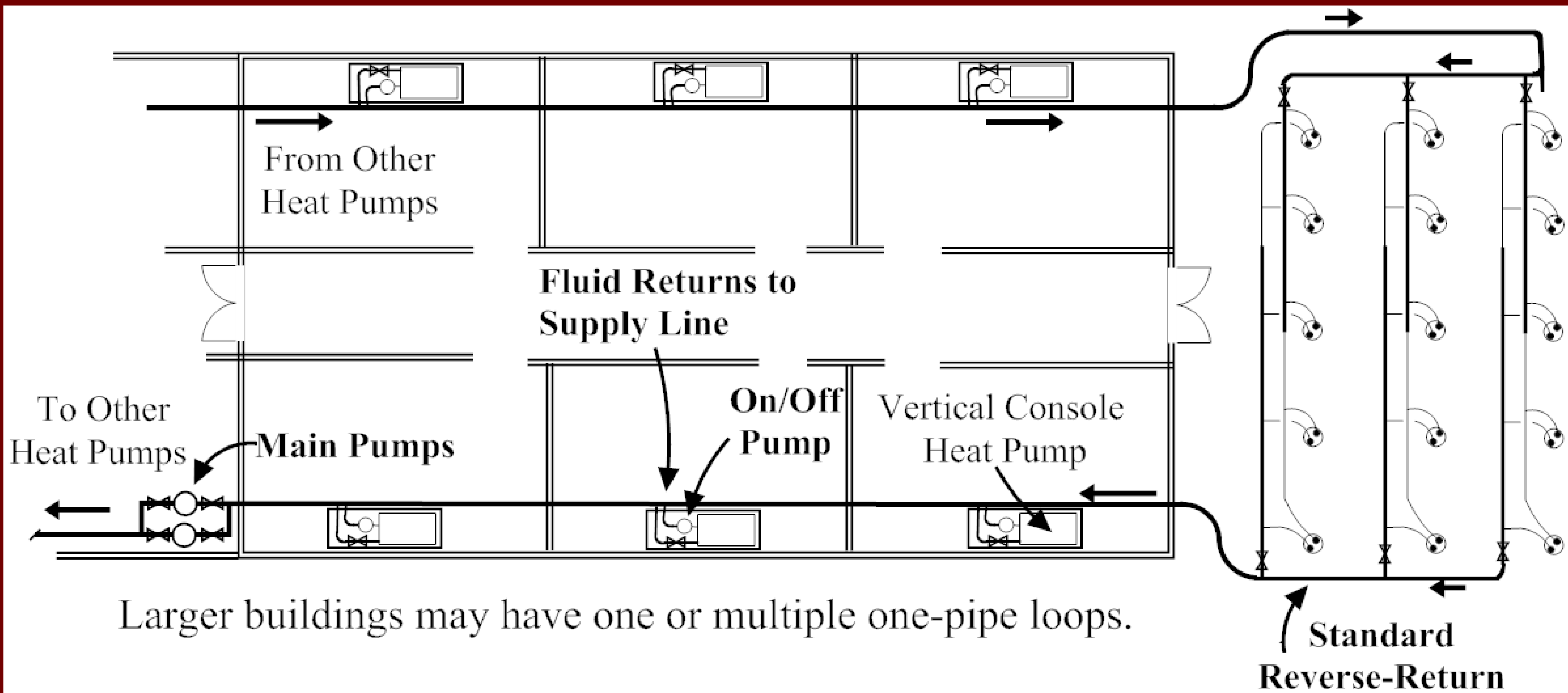
Simple Installation, Control and Maintenance,
Takes Advantage of Load Diversity,
Relatively Low Installation Costs



Multiple Units with Pumps on Common Loop
Larger buildings may have multiple common loops.

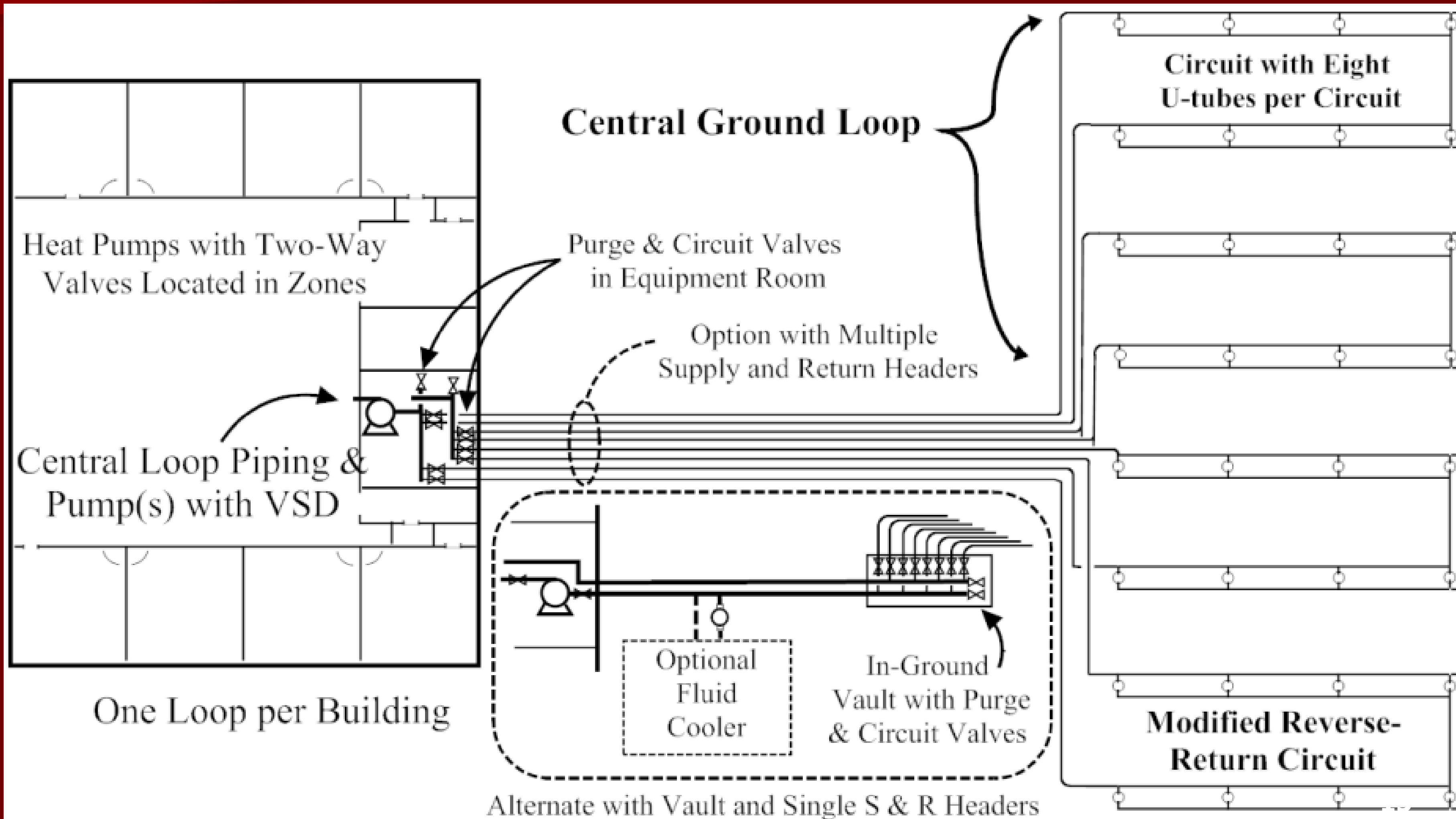
One-Pipe Loop Option

Second Highest Average Energy Star Rating, Simple Installation, Control and Maintenance, Takes Advantage of Load Diversity, Relatively Low Installation Costs

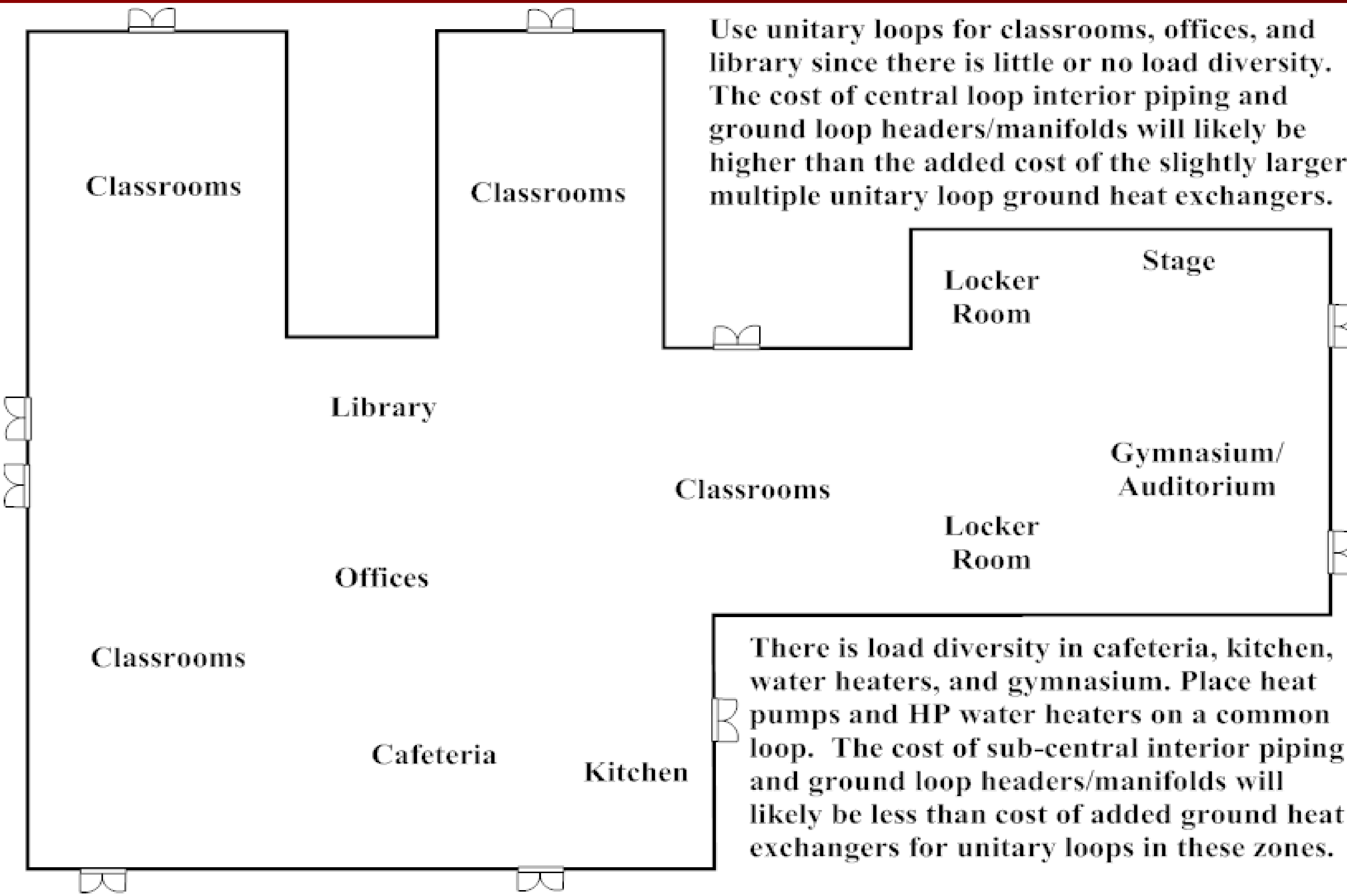


Central Loop Option

Lowest Average ENERGY STAR® Rating, Highest Installation Costs, Takes Advantage of Load Diversity, Popular with Engineers New to GSHP Design



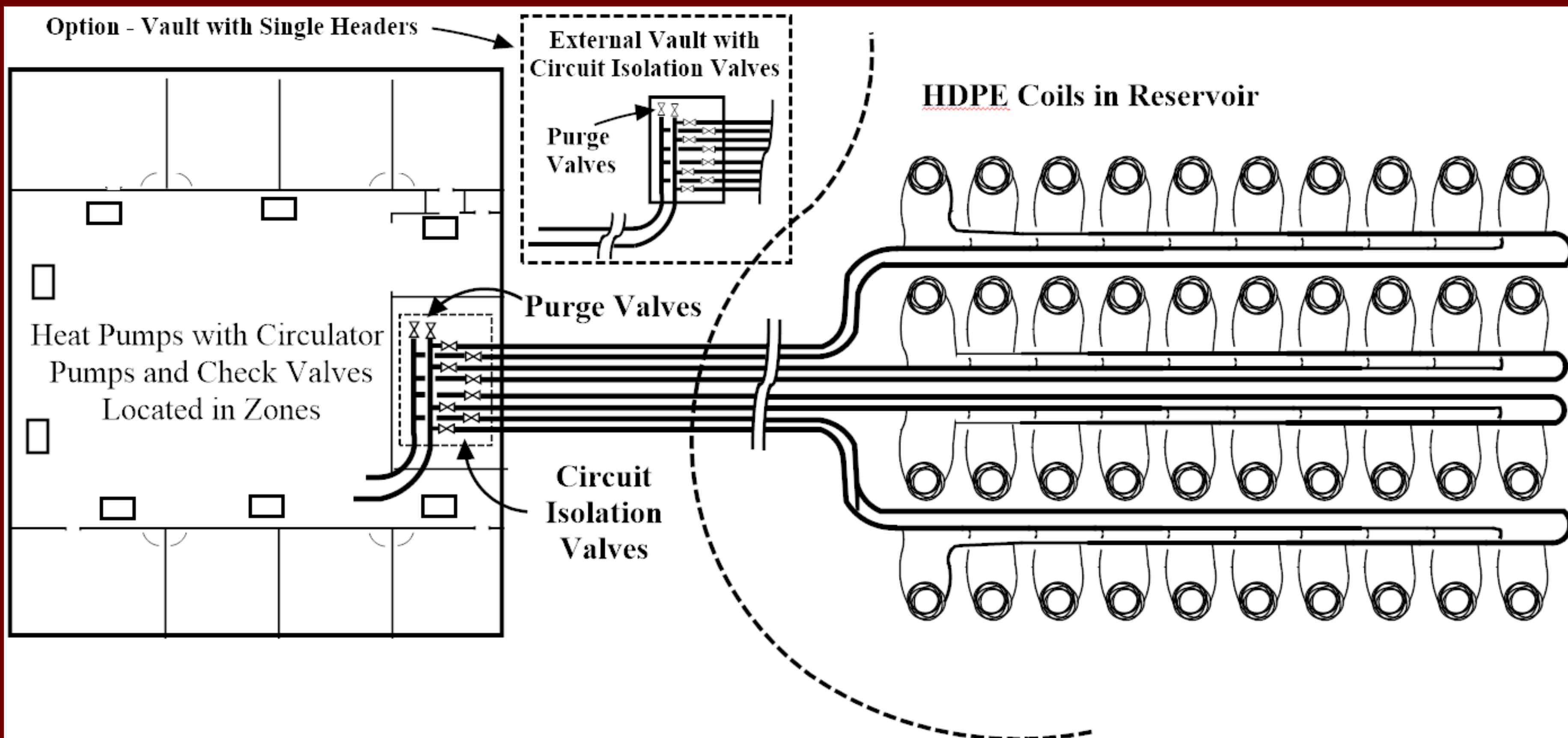
Buildings with Multiple Loop Options



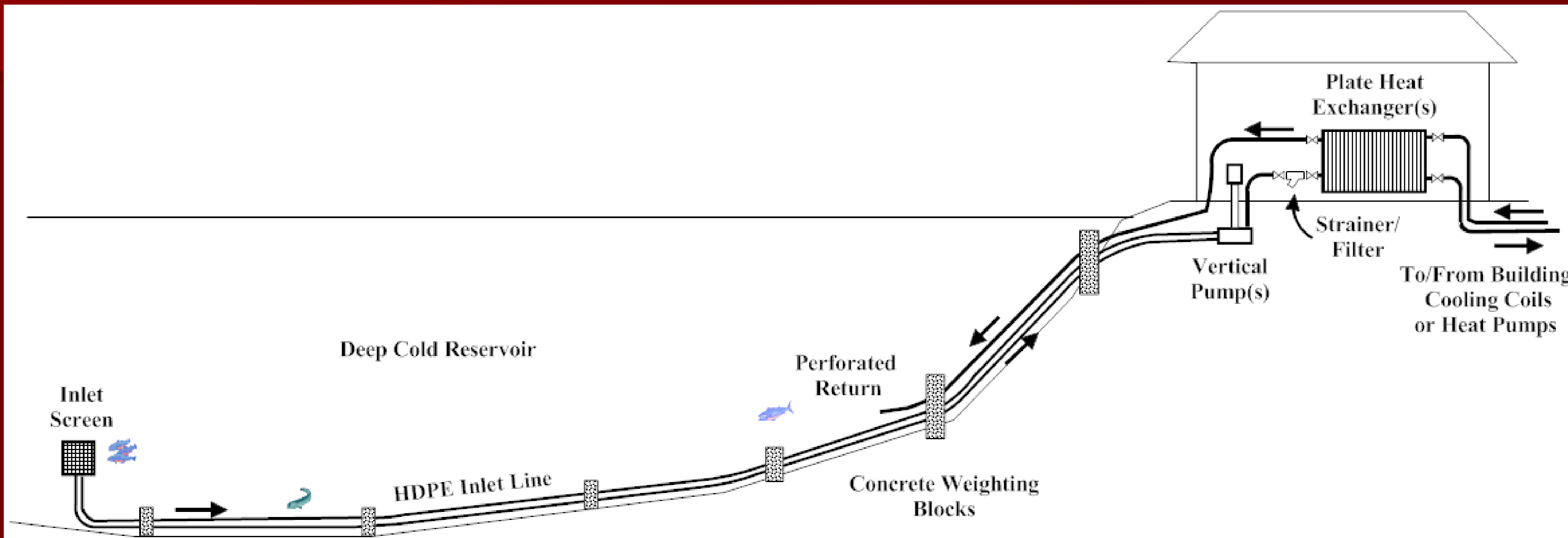
Use unitary loops for classrooms, offices, and library since there is little or no load diversity. The cost of central loop interior piping and ground loop headers/manifolds will likely be higher than the added cost of the slightly larger multiple unitary loop ground heat exchangers.

There is load diversity in cafeteria, kitchen, water heaters, and gymnasium. Place heat pumps and HP water heaters on a common loop. The cost of sub-central interior piping and ground loop headers/manifolds will likely be less than cost of added ground heat exchangers for unitary loops in these zones.

Surface Water Heat Pumps (SWHPs) Common Loop with Equipment Room Manifold



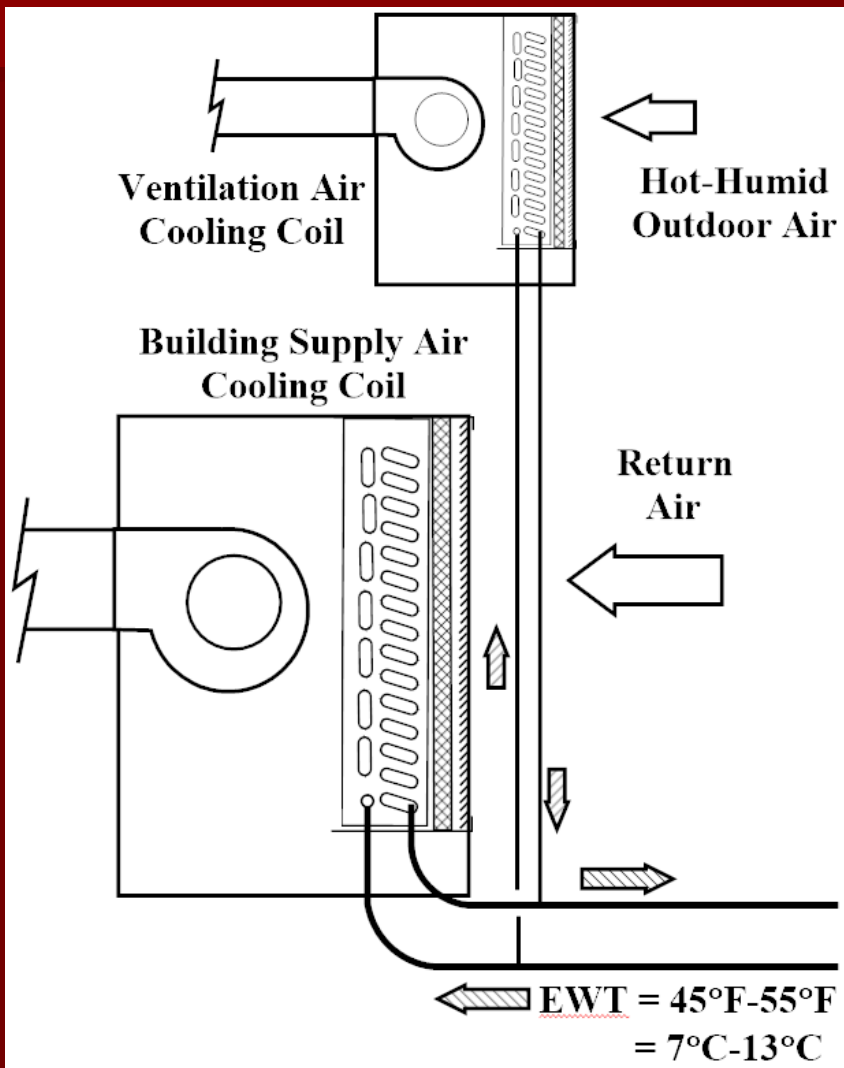
Open Loop Surface Water Direct Cooling (and Possibly Heat Pump Operation*)

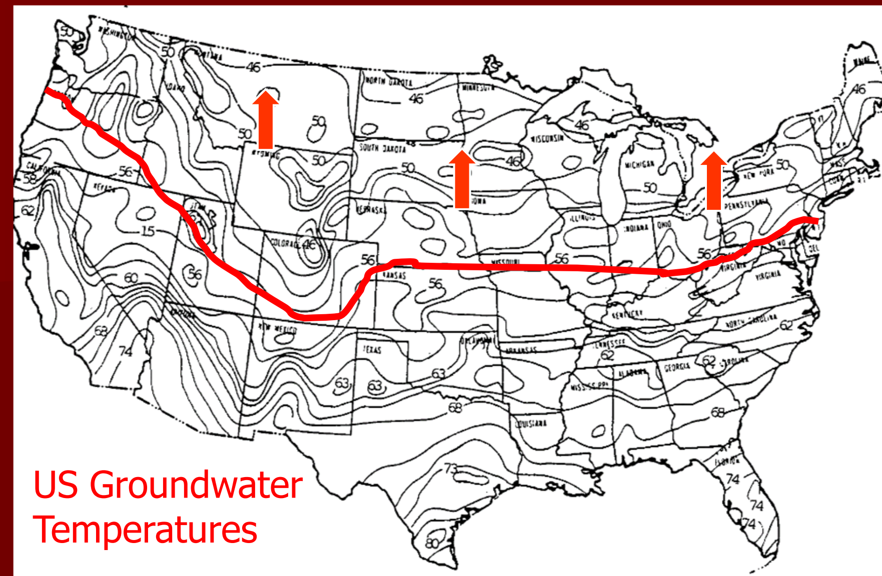


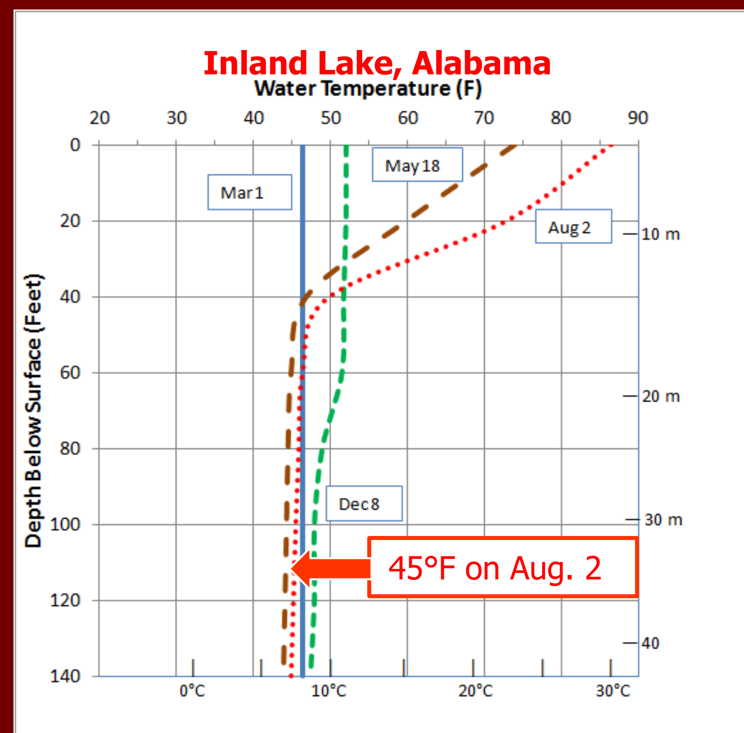
* In heating for open loop surface water heat pumps:

- Coil Leaving Water Temperature (°F) ≈ Entering Water Temp (°F) – 18 ÷ gpm/ton
- LWT must be 3°F to 5°F above 32°F to prevent frost on water coil
- Thus, minimum EWT must be at least 42°F to 44°F, which does not occur in many lakes.

Direct Cooling of Outside and Primary Air with Cold Water from Deep Reservoirs and Northern Ground Water







Preliminary Evaluation
Choosing the Optimum GSHP System
GSHP Site and HVAC System Evaluation

- GCHP: Size of building and site, regulations, estimated loop size, drilling depth, thermal property test
- Equipment Options: Water-to-air heat pumps, water-to-water heat pumps, chiller, hybrid-fluid cooler/cooling tower
- Distribution Options: Unitary forced air, fan coil units, air handlers with VAV, in-floor heat, chilled beam
- Efficiency and cost estimate of heat exchanger and equipment

Preliminary Ground-Coupled Heat Pump Considerations

- Regulations
- Size, type, and efficiency of building envelope and loads
- Size of ground loop site
- Geological and hydro-geological formation properties
- Economic drilling depths
- Thermal property test

Ground-Coupled Heat Pump Example Site Area Estimate for a 10,000 ft² (930 m²) Office

- Example cooling load (q_{lc}) 21 tons (73 kW)
- Local GCHP designs average around 220 ft/ton of vertical bore (L_{bore}/q) for offices
- Thus, the total bore estimate would be 4620 ft (1400 m)
- Local drillers are comfortable with bore depths (D_{bore}) of 300 ft (90 m)
- The number of bores (N_{bore}) will likely 16 (4620 ft ÷ 300 ft/bore = 15.4)
- Bores separation (S_{bore}) should be 20 ft (6 m)

$$\textbf{Site Area} \approx q_{lc} \times (L_{bore}/q) \times S_{bore}^2 \div D_{bore}$$

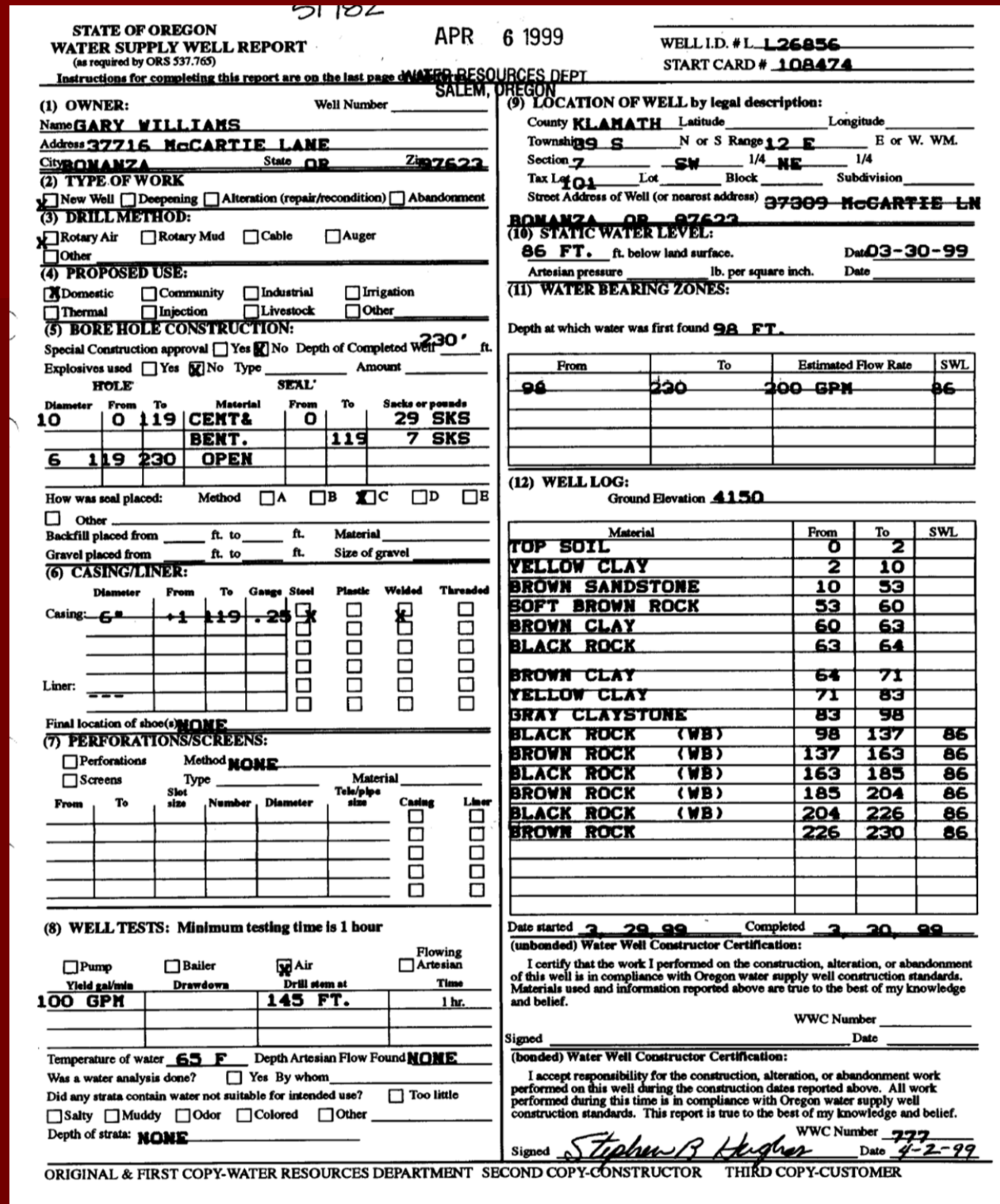
$$\text{Site Area} \approx 21 \text{ tons} \times 220 \text{ ft/ton} \times (20 \text{ ft})^2] \div 300 \text{ ft}$$

$$\approx 6160 \text{ ft}^2 \ (570 \text{ m}^2/0.14 \text{ acre})$$

Formation Properties and Drilling Conditions

Abundant Info from State Geological Surveys

Well Logs



51182

STATE OF OREGON
WATER SUPPLY WELL REPORT
(as required by ORS 537.765)

APR 6 1999

WATER RESOURCES DEPT
SALEM, OREGON

WELL I.D. # L L26856
START CARD # 108474

Instructions for completing this report are on the last page of this form.

(1) OWNER: Well Number
Name GARY WILLIAMS
Address 37716 McCARTIE LANE
City BONANZA State OR Zip 97623

(2) TYPE OF WORK
[X] New Well [ ] Deepening [ ] Alteration (repair/recondition) [ ] Abandonment

(3) DRILL METHOD:
[X] Rotary Air [ ] Rotary Mud [ ] Cable [ ] Auger [ ] Other

(4) PROPOSED USE:
[X] Domestic [ ] Community [ ] Industrial [ ] Irrigation [ ] Thermal [ ] Injection [ ] Livestock [ ] Other

(5) BORE HOLE CONSTRUCTION:
Special Construction approval [ ] Yes [X] No Depth of Completed Well 230' ft.
Explosives used [ ] Yes [X] No Type Amount

HOLE Diameter	From	To	SEAL Material	From	To	Sacks or pounds
10	0	119	CEMT&	0		29 SKS
			BENT.		119	7 SKS
6	119	230	OPEN			

How was seal placed: Method [ ] A [ ] B [X] C [ ] D [ ] E
[ ] Other
Backfill placed from ft. to ft. Material
Gravel placed from ft. to ft. Size of gravel

(6) CASING/LINER:

	Diameter	From	To	Gauge	Steel	Plastic	Welded	Threaded
Casing:	6"	+1	119	.25	X		X	
Liner:	---							

Final location of shoe(s) NONE

(7) PERFORATIONS/SCREENS:
[ ] Perforations Method NONE
[ ] Screens Type Material

From	To	Slot size	Number	Diameter	Tele/pipe size	Casing	Liner

(8) WELL TESTS: Minimum testing time is 1 hour
[ ] Pump [ ] Bailer [X] Air [ ] Flowing Artesian

Yield gal/min	Drawdown	Drill stem at	Time
100 GPM		145 FT.	1 hr.

Temperature of water 65 F Depth Artesian Flow Found NONE
Was a water analysis done? [ ] Yes By whom
Did any strata contain water not suitable for intended use? [ ] Too little
[ ] Salty [ ] Muddy [ ] Odor [ ] Colored [ ] Other
Depth of strata: NONE

(9) LOCATION OF WELL by legal description:
County KLAMATH Latitude Longitude
Township 39 S N or S Range 12 E E or W. WM.
Section 7 SW 1/4 NE 1/4
Tax Lot 101 Lot Block Subdivision
Street Address of Well (or nearest address) 37309 McCARTIE LN BONANZA OR 97623

(10) STATIC WATER LEVEL:
86 FT. ft. below land surface. Date 03-30-99
Artesian pressure lb. per square inch. Date

(11) WATER BEARING ZONES:
Depth at which water was first found 98 FT.

From	To	Estimated Flow Rate	SWL
98	230	200 GPM	86

(12) WELL LOG:
Ground Elevation 4150

Material	From	To	SWL
TOP SOIL	0	2	
YELLOW CLAY	2	10	
BROWN SANDSTONE	10	53	
SOFT BROWN ROCK	53	60	
BROWN CLAY	60	63	
BLACK ROCK	63	64	
BROWN CLAY	64	71	
YELLOW CLAY	71	83	
GRAY CLAYSTONE	83	98	
BLACK ROCK (WB)	98	137	86
BROWN ROCK (WB)	137	163	86
BLACK ROCK (WB)	163	185	86
BROWN ROCK (WB)	185	204	86
BLACK ROCK (WB)	204	226	86
BROWN ROCK	226	230	86

Date started 3-29-99 Completed 3-30-99

(unbonded) Water Well Constructor Certification:
I certify that the work I performed on the construction, alteration, or abandonment of this well is in compliance with Oregon water supply well construction standards. Materials used and information reported above are true to the best of my knowledge and belief.
WWC Number
Signed Date

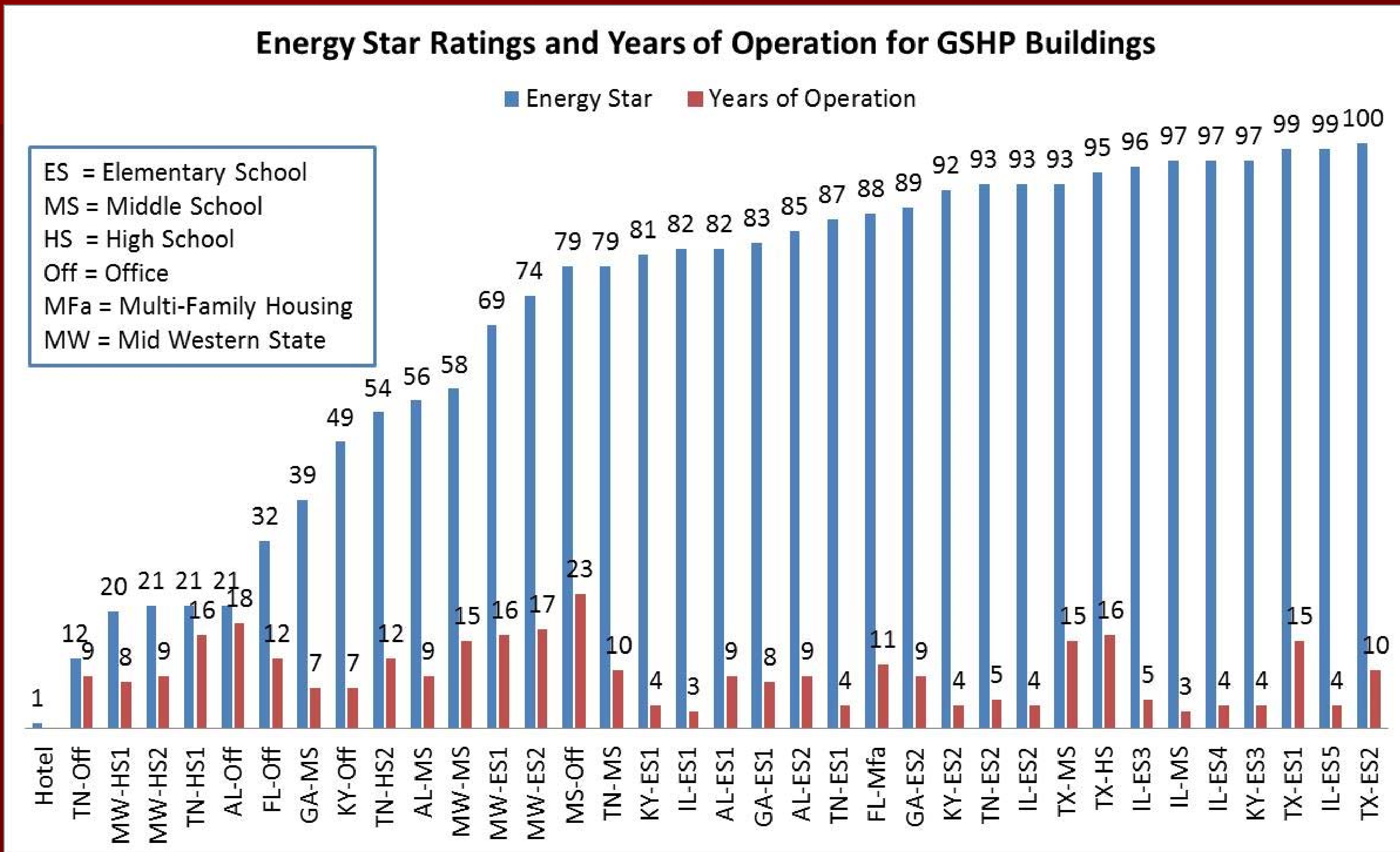
(bonded) Water Well Constructor Certification:
I accept responsibility for the construction, alteration, or abandonment work performed on this well during the construction dates reported above. All work performed during this time is in compliance with Oregon water supply well construction standards. This report is true to the best of my knowledge and belief.
WWC Number 777
Signed Stephen R Hughes Date 4-2-99

ORIGINAL & FIRST COPY-WATER RESOURCES DEPARTMENT SECOND COPY-CONSTRUCTOR THIRD COPY-CUSTOMER

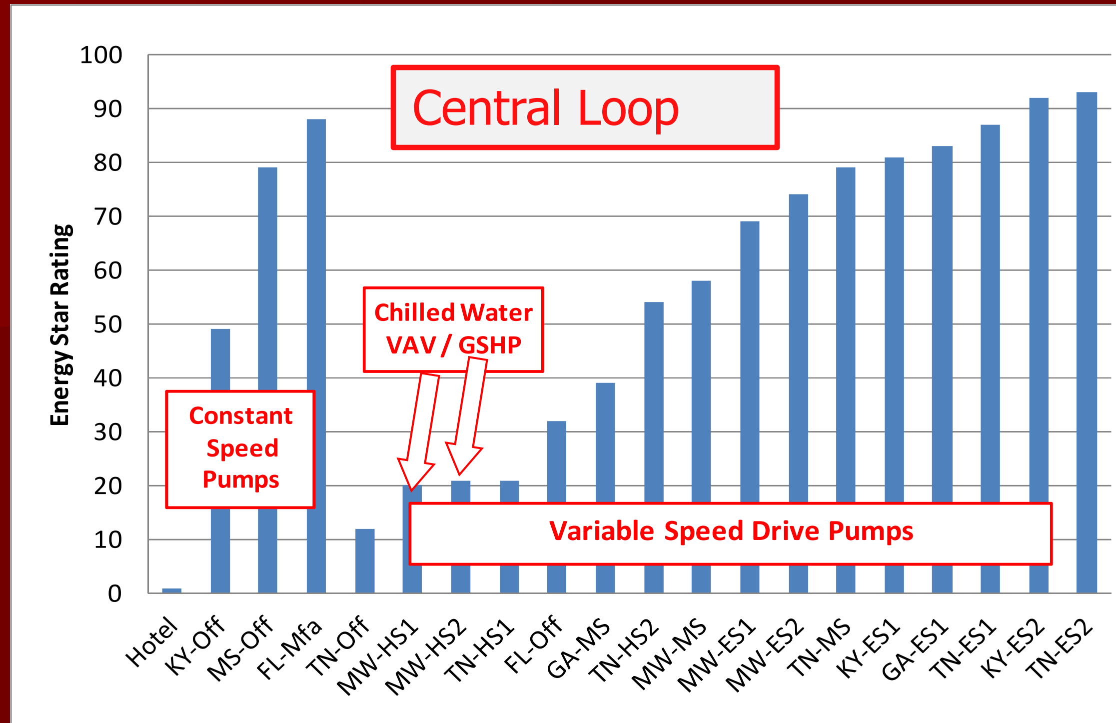
GSHP System Equipment and Distribution Options

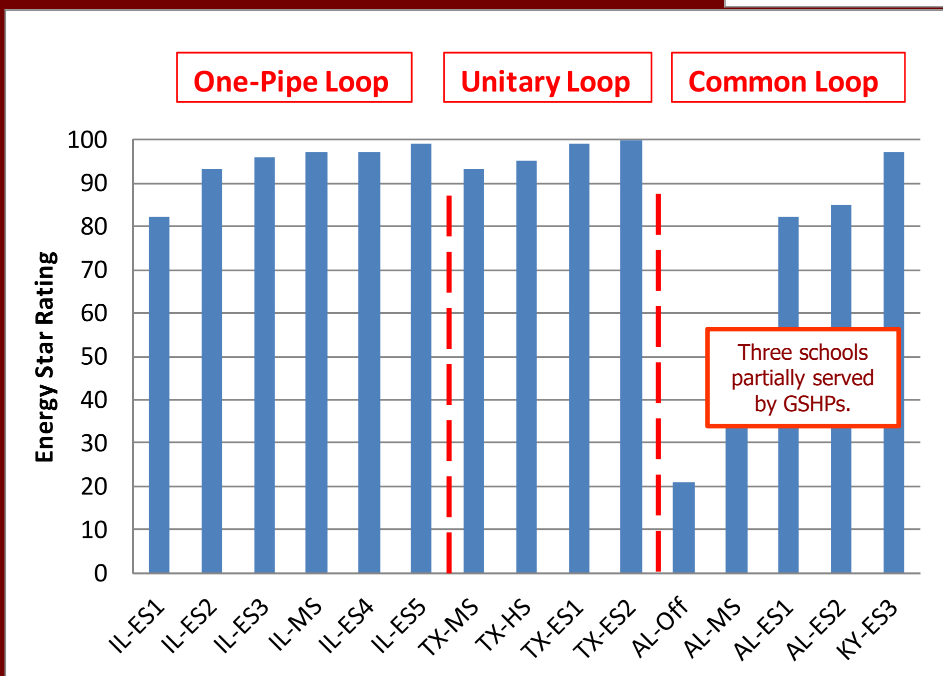
- **The HVAC system must be efficient in order for the GSHP to be efficient.**
- Systems with large amounts of fan and pump power will require much larger ground loops to dissipate the additional heat in the cooling mode.
- Systems with large amount of fan power will operate in heating much fewer hours and thus fail to remove sufficient heat from the ground loop to balance cooling heat rejection.
- The spreadsheet tool HVACSytemEff.xlsx is available to transpose equipment specifications (heat pumps, fans, pumps, etc.) to calculate ***system*** **efficiency** and ensure the GSHP system design will perform as advertised.

Long-Term GSHP Performance Survey

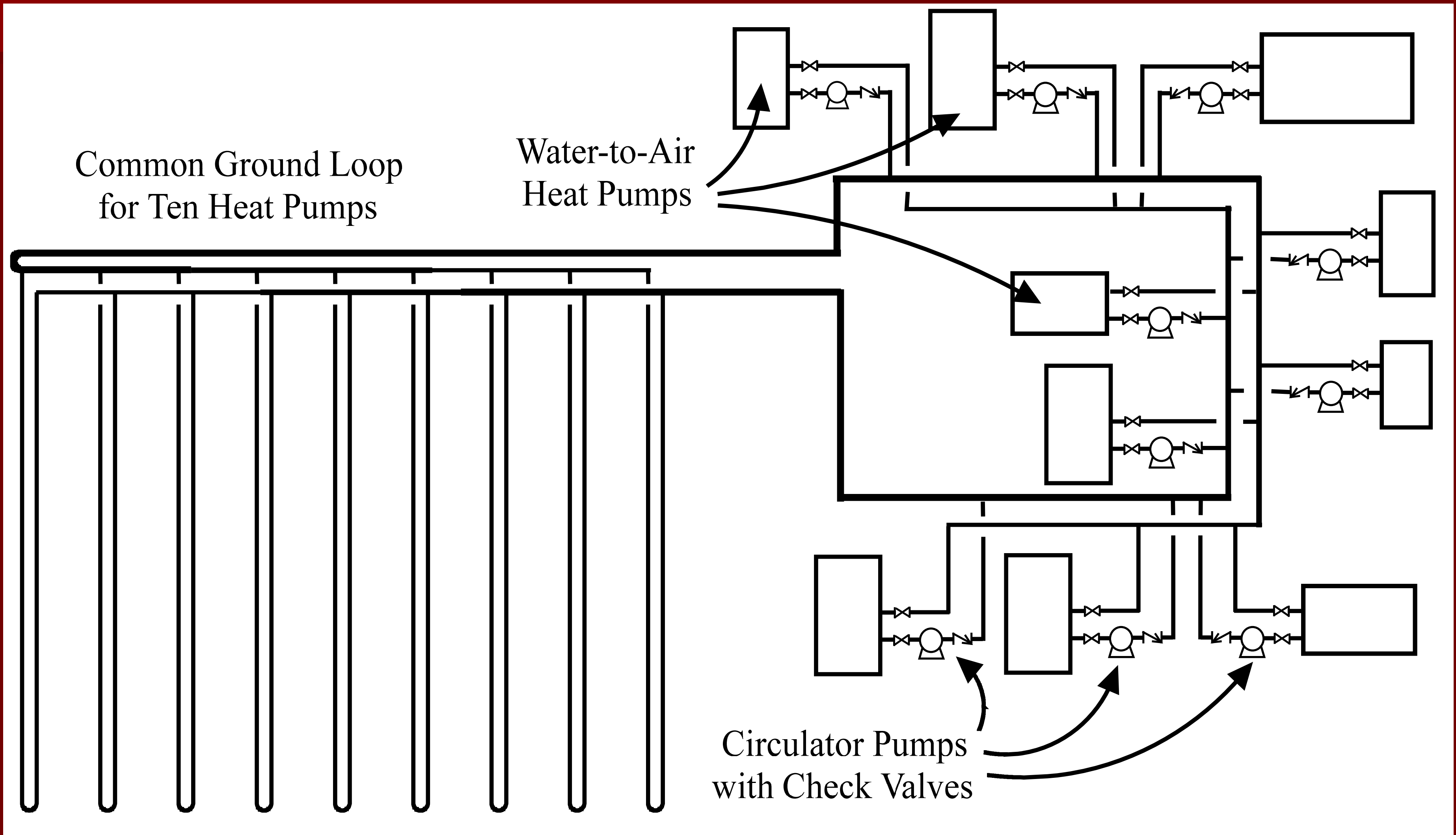


ENERGY STAR Rating and GCHP Loop Type





Performance Prediction
Heat Pump GSHP System Efficiency
Example 1: 200 WAHPs, 20 Common Loops

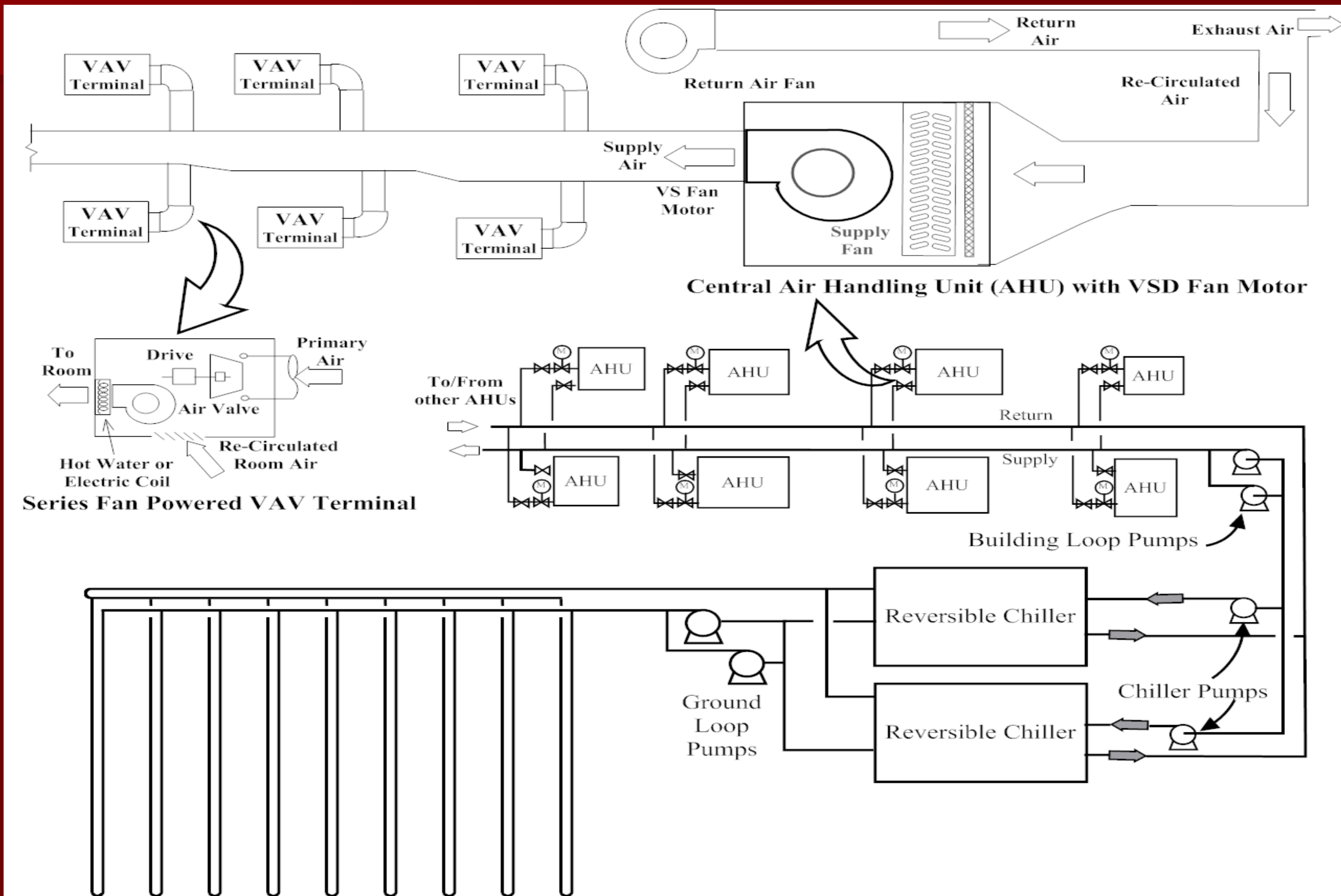


Common Loop GSHP System Efficiency
EER = 14.6 Btu/W·h (COP = 4.27)

HVAC System Cooling Efficiency Calculator (Reference: *HVAC Simplified*, ASHRAE, 2006)

Item												
			Yellow Colored Cells for Input					**Do Not Type in Blue (Output) Cells**				
Item		Enter Chiller Data in Cells Below			**OR**	Enter AC/HP Data						
1	Chillers or Heat Pumps **Click Here for Explanation**	Qty.	kW/ton	Tons		Qty.	EER	kBtu/h	kW-each	kW-total	kBtu/h	tons
	WC chillers based on CoLWT=95 F*, ChWLT=44 F*				---	50	19.2	28.3	1.5	73.7	1415.0	117.9
	AC chillers based on OAT = 95 F*, ChWLT = 44 F*				---	100	19.6	34.5	1.8	176.0	3450.0	287.5
	Enter EER at 95 F* (air source) or EER at 86 F* (WSHP)					50	19.2	40.6	2.1	105.7	2030.0	169.2
	*Enter ratings at non-standard conditions when appropriate.				---				0.0	0.0	0.0	0.0
2a	Air Handling Unit Fans (≥1.0 hp) **Click Here**		Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr. (%)	**η VSD (%)**	hp-each	---	---	---	---
	Fan power added here if corrections not made to EER and capacity							0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
2b	DX Coil, Water Coil, or VAV Fans (<1.0 hp) **Click Here**		Air Flow (cfm)	TP (in. wtr)	η wire-air (%)	**OR** hp-each	η mtr. (%)		---	---	---	---
	Systems with Unitary ACs or Heat Pumps	50	900	0.6	30.0%			0.28	0.21	10.6	-36.1	-3.0
		100	1200	0.7	30.0%			0.44	0.33	32.9	-112.2	-9.4
		50	1300	0.7	30.0%			0.48	0.36	17.8	-60.8	-5.1
3	Return Air Fans - Enter exhaust air % →	20%	Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr. (%)	**η VSD (%)**		---	---	---	---
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
4	Chilled Water Pumps		Wtr. Flow (gpm)	ΔH (ft. wtr)	η pump (%)	η mtr. (%)	**η VSD (%)**		---	---	---	---
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
5	Condenser or Ground Loop Water Pumps		Wtr.Flow (gpm)	ΔH (ft. wtr)	η pump (%)	η mtr. (%)	**η VSD (%)**		---	---	Click Here	
		50	8	30	50.0%	50.0%	100.0%	0.12	0.18	9.0	---	---
		100	9	30	50.0%	50.0%	100.0%	0.14	0.20	20.3	---	---
		50	11	30	50.0%	50.0%	100.0%	0.17	0.25	12.4	---	---
6	Condenser (or Fluid Cooler/Cooling Tower) Fan	0	Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr. (%)	**η VSD (%)**	hp-each	---	---	---	---
		0	---	---	---	75.0%	100.0%		0.00	0.0	---	---
			---	---	---				0.00	0.0	---	---
			---	---	---				0.00	0.0	---	---
										kW	kBtu/h	tons
								System Totals		**458.6**	**6685.9**	**557.2**
				kW/ton :	**0.82**	**EER =**	**14.6**	**Btu/W-**	**COP =**	4.27		
		ASHRAE 90.1 check		Q (cfm) =	230000	Fan hp =	82	hp/1000cf	0.36			

Performance Prediction
Chilled-Water VAV GSHP System Efficiency
Example 2: 2 WC-Chillers, 16 AHUs, Central Loop



CWVAV—Central Loop GSHP System Efficiency EER = 7.8 Btu/W·h (COP = 2.28)

HVAC System Cooling Efficiency Calculator (Reference: *HVAC Simplified* , ASHRAE, 2006)

Item												
			Yellow Colored Cells for Input						**Do Not Type in Blue (Output) Cells**			
Item		Enter Chiller Data in Cells Below			**OR**	Enter AC/HP Data						
1	Chillers or Heat Pumps **Click Here for Explanation**	Qty.	kW/ton	Tons		Qty.	EER	kBtu/h	kW-each	kW-total	kBtu/h	tons
	WC chillers based on CoLWT=95 F*, ChWLT=44 F*	2	0.5	340	---				170.0	340.0	8160.0	680.0
	AC chillers based on OAT = 95 F*, ChWLT = 44 F*				---				0.0	0.0	0.0	0.0
	Enter EER at 95 F* (air source) or EER at 86 F* (WSHP)								0.0	0.0	0.0	0.0
	*Enter ratings at non-standard conditions when appropriate.				---				0.0	0.0	0.0	0.0
2a	Air Handling Unit Fans (≥1.0 hp) **Click Here**		Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr. (%)	**η VSD (%)**	hp-each	---	---	---	---
		4	40000	5	75.0%	93.0%	98.0%	41.99	34.37	137.5	-469.1	-39.1
		4	20000	4	75.0%	92.0%	98.0%	16.80	13.90	55.6	-189.7	-15.8
		8	4000	2	70.0%	88.0%	98.0%	1.80	1.56	12.5	-42.5	-3.5
2b	DX Coil, Water Coil, or VAV Fans (<1.0 hp) **Click Here**		Air Flow (cfm)	TP (in. wtr)	η wire-air (%)	**OR** hp-each	η mtr. (%)		---	---	---	---
	Systems with Unitary ACs or Heat Pumps	50	1600	0.5	30.0%			0.42	0.31	15.7	-53.4	-4.5
		120	1200	0.5	28.0%			0.34	0.25	30.2	-103.1	-8.6
		60	800	0.5	25.0%			0.25	0.19	11.3	-38.5	-3.2
3	Return Air Fans - Enter exhaust air % ➔➔➔	20%	Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr. (%)	**η VSD (%)**		---	---	---	---
		8	34000	2.5	75.0%	92.0%	97.0%	17.85	14.92	119.4	-325.8	-27.2
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
4	Chilled Water Pumps		Wtr. Flow (gpm)	ΔH (ft. wtr)	η pump (%)	η mtr. (%)	**η VSD (%)**		---	---	---	---
		2	825	100	70.0%	90.0%	97.0%	29.76	25.43	50.9	-173.5	-14.5
		2	825	50	70.0%	90.0%	97.0%	14.88	12.72	25.4	-86.8	-7.2
								0.00	0.00	0.0	0.0	0.0
5	Condenser or Ground Loop Water Pumps		Wtr.Flow (gpm)	ΔH (ft. wtr)	η pump (%)	η mtr. (%)	**η VSD (%)**		---	---	Click Here	
		2	1000	100	70.0%	90.0%	97.0%	36.08	30.83	61.7	---	---
								0.00	0.00	0.0	---	---
								0.00	0.00	0.0	---	---
6	Condenser (or Fluid Cooler/Cooling Tower) Fan	0	Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr. (%)	**η VSD (%)**	hp-each	---	---	---	---
		0	---	---	---	75.0%	100.0%		0.00	0.0	---	---
			---	---	---				0.00	0.0	---	---
			---	---	---				0.00	0.0	---	---
										kW	kBtu/h	tons
								System Totals		**860.0**	**6677.6**	**556.5**
				kW/ton :	1.55	EER =	7.8	Btu/W-h	COP =	2.28		

GSHP Costs: 1995 to 2011

- The average ground heat exchanger cost in the recent survey was 26% of total GSHP cost and increased by 50% (3% per year) since 1995
- The average HVAC cost in the recent survey was 74% of the total GSHP system cost and has increased by 177% (11% per year) since 1995
- Using logic (an important tool for engineering), cost optimization should include, and possibly concentrate, on the HVAC component of GSHPs

GSHP Cost Versus Performance

- Open access to cost information (operating, HVAC components, and ground loops) is critical
- Currently, this information is limited and typically not reported (why not do it—isn't that hard)
- ENERGY STAR rating is simple indicator of ***system*** performance with reasonable accuracy
- ASHRAE Standard 90.1-2016 compliance is likely a poor predictor of performance because it deals with just the parts and not the whole ***system***
- Quality engineering practice can often reduce both installation and operating cost via **KISS**

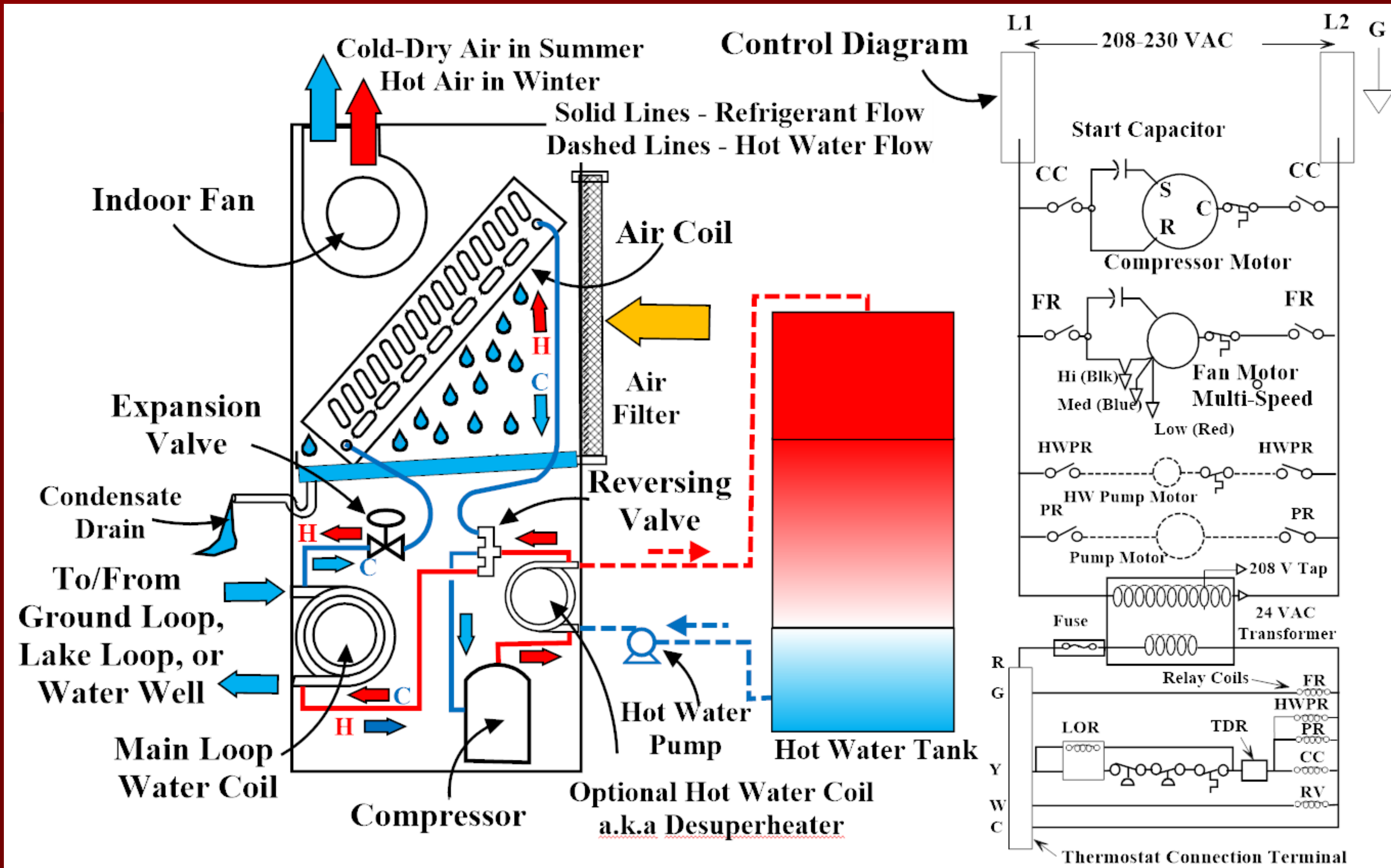
Questions?

Comments?

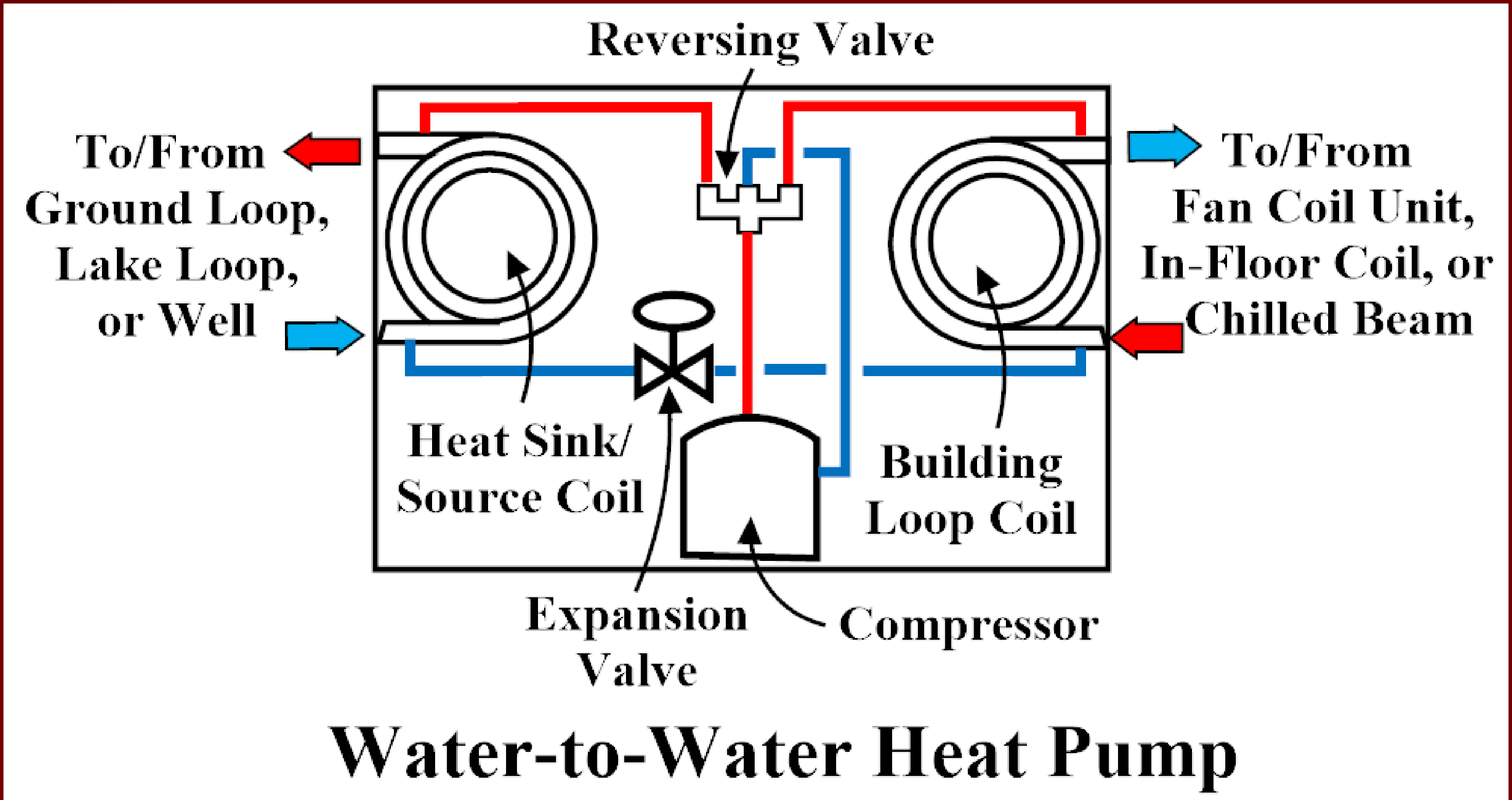
Session 2

EQUIPMENT FOR GROUND-SOURCE APPLICATIONS

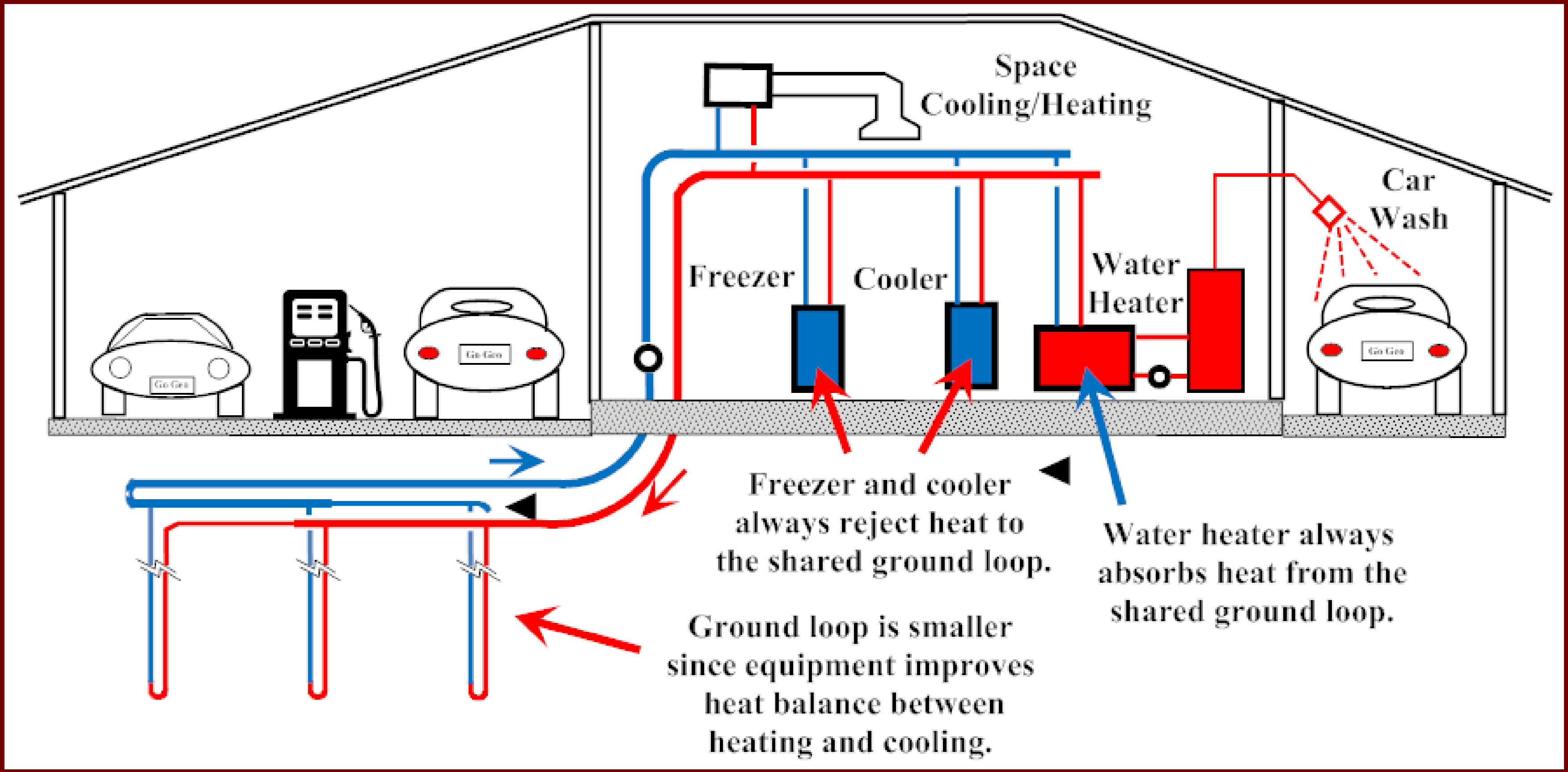
Water-to-Air Heat Pump Circuit and Controls



Water-to-Water Heat Pump Circuit



Convenience Store Application with Heating and Cooling Requirements



Heat Pump Types (with Pictures)

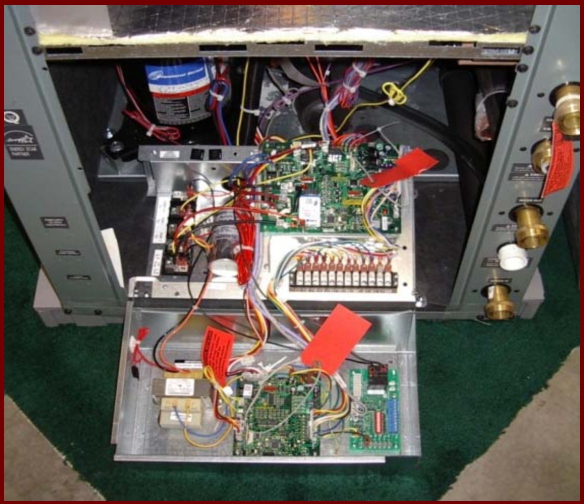
Well-Located Heat Pumps

Heat Pumps for Larger Spaces

Easy to Service Heat Pumps

Poorly Located Heat Pumps

Water-to-Water Heat Pumps



Hard to Service Heat Pumps

Revenge of the Overextended Service Tech (after the Fan Motor Burned Out the Second Time)

Happy Service Techs and Supervisor: Removable Classroom WAHP Refrigerant Circuit

Table 2.1 ISO 13256-1 Rating Conditions for Water-to-Air Heat Pumps

Entering Liquid & Air Temperatures	WLHP Water Loop	GWHP Groundwater	GLHP Ground Loop	GLHP-PL (Part-Load)
ELT - Cooling Exterior Loop	86°F (30°C)	59°F(15°C)	77°F(25°C)	68°F (20°C)
ELT - Heating Exterior Loop	68°F (20°C)	50°F (10°C)	32°F (0°C)	41°F (5°C)
EAT - Cooling Dry bulb/wet bulb	80.6/66.2°F (27/19°C)			
EAT - Heating	68°F (20°C)			

Note: Values for TC, EER, HC and COP do not include fan power or pump required to circulate air and water through the air distribution system and piping loop. Values for TC do not include the loss of capacity due to the heat of the fan. The power to circulate air and water through unit itself is included in the calculation.

Table 2.2 ISO 13256-2 Rating Conditions for Water-to-Water Heat Pumps

Entering Liquid Temperatures	WLHP Water Loop	GWHP Groundwater	GLHP Ground Loop	GLHP-PL (Part-Load)
ELT - Cooling Exterior Loop	86°F (30°C)	59°F(15°C)	77°F(25°C)	68°F (20°C)
ELT - Heating Exterior Loop	68°F (20°C)	50°F (10°C)	32°F (0°C)	41°F (5°C)
ELT - Cooling Interior Loop	53.6°F (12°C)			
ELT - Heating Interior Loop	104°F (40°C)			

Note: Values for TC, EER, HC and COP do not include pump power required to circulate water through the exterior and interior piping loops. Likewise the fan power of terminal units (fan coil units, air handling units) is not included. Values for TC do not include the loss of capacity due to the interior piping loop pump heat or air terminal unit fan heat.

Note the ELT in heating is 104°F (40°C). Thus, LLT would be approximately 114°F (46°C), and both heating capacity and COP should be corrected if coils are specified for higher (or lower) temperatures. In cooling, the ELT of 53.6°F (12°C) and resulting LLT of approximately 43.6°F (6°C) are nearly the same as standard values used for chilled-water coils (54°/44°F).

Engineers, Activate Your BS Detectors
Variable-Speed Heat Pumps are Only More Efficient when Loop Temperatures are Mild and Air and Water Flows are Very High

				Single Speed Water-to-Air Heat Pumps											
				Water Loop Heat Pump				Ground Water Heat Pump				Ground Loop Heat Pump			
				Clg - 86°F ELT		Htg - 68°F ELT		Clg - 59°F ELT		Htg - 50°F ELT		Clg-77°F (FL)		Htg-32°F (FL)	
Mod	Load	cfm	gpm	TC	EER	HC	COP	TC	EER	HC	COP	TC	EER	HC	COP
15	Full	500	4	14.4	16.5	18.5	5.3	16.7	27.0	15.5	4.7	15.0	18.1	12.0	4.0
18	Full	600	5	18.0	16.5	23.0	5.3	21.0	26.8	19.0	4.7	18.5	19.0	14.7	4.1
22	Full	850	8	20.7	17.5	25.3	6.2	23.5	30.0	19.8	5.3	21.7	21.0	15.0	4.0
30	Full	900	8	28.3	19.2	32.7	5.8	31.3	28.8	25.8	5.0	29.4	21.9	20.0	4.0
36	Full	1200	9	34.5	**19.6**	38.0	6.1	37.2	30.1	30.3	5.2	35.0	22.0	24.1	**4.4**
42	Full	1300	11	40.6	19.2	44.1	5.9	45.2	29.5	34.9	5.2	42.0	21.4	27.5	4.2
48	Full	1500	12	47.0	17.5	55.4	5.5	52.0	26.1	45.1	4.8	49.3	19.7	35.3	4.0
60	Full	1800	15	64.3	17.2	69.8	5.4	72.0	26.1	55.1	4.7	66.8	19.5	43.3	3.9
70	Full	2000	18	70.6	16.0	84.3	5.1	79.1	23.8	66.1	4.4	73.2	18.2	52.0	3.7

		cfm			Variable Speed Water-to-Air Heat Pumps											
		Clg.	Htg.		WLHP & GWHP Part-Load (PL) ELTs = Full-Load (FL) ELTs								Clg-68°F (PL)		Htg-[illegible]°F (PL)	
36	Full	1300	1500	9	32.0	**18.0**	50.0	5.3	38.0	31.5	41.0	4.6	36.0	22.0	32.0	**3.5**
36	Part	**1300**	**1500**	9	11.0	**21.0**	17.0	7.5	13.0	47.2	14.0	5.9	14.0	37.0	13.0	**5.3**
48	Full	1500	1800	12	41.0	17.6	67.0	5.0	49.0	31.7	55.0	4.3	46.0	21.7	43.0	3.6
48	Part	1500	1800	12	16.0	22.5	24.0	7.6	19.2	53.2	19.0	5.9	19.0	41.0	16.0	5.3
60	Full	1800	2200	15	50.0	16.3	78.0	4.8	60.0	28.6	65.0	4.3	56.0	19.4	51.0	3.5
60	Part	1800	2200	15	20.0	21.7	29.0	7.5	23.2	45.8	23.0	6.0	23.0	36.0	20.0	5.1

Cooling EAT=80.6°F (db)/66.2°F (wb), Heating EAT= 68°F (db), TC & HC in Btu/h × 1000, EER in Btu/W-h, COP in W/W

1400 cfm/ton

10 gpm/ton

0.9 tons

Compressor Overspeed

Converting Full Load Rated Performance* to Actual Performance—Three Options

- Long way: Lots of manual calculation
- Short cut: Single point correction**—Less accurate
  - Multiply rated TC by 0.93
  - Multiply rated EER by 0.80
  - Multiply rated HC by 1.03
  - Multiply rated COP by 0.89
- Spreadsheet software: Faster and more accurate

*Corrections for part-load operation not possible because rated part-load airflow rates are typically too high to extrapolate down to useful values.

**Correct from rated conditions to EAT (db/wb) from 80.6°/66.2°F to 75°/63°F (24°/17°C) and ESP from 0.0 in. w.g. to 0.5 in. w.g. (125 Pa)

Another Tool
WAHP Performance Correction Spreadsheet

Rated Performance

HC32	COP32	HC50	COP50	HC68	COP68
43.3	3.9	55.1	4.7	69.8	5.4

gpm	cfm	TC59	EER59	TC77	SC77	EER77	TC86	EER86
15	1800	72.0	26.1	66.8		19.5	64.3	17.2

Corrected Performance (includes fan and pump power, fan heat)

GLHP Rated Performance		
Model#	ECM-60	
TC-77°F	66.8	kBtu/h
SC-77°F	0	kBtu/h
EER-77°F	19.5	Btu/W-h
HC-32°F	43.3	kBtu/h
COP-32°F	3.9	W/W
WtrFlow	15.0	gpm
AirFlow	1800	cfm
GpmPTonR	2.7	
CfmPTonR	323	
GpmPTonA	2.7	

Operating Conditions		
ELTClg	80.0	°F
ELTHtg	43.0	°F
EATdbClg	75.0	°F
EATwbClg	63.0	°F
EATHtg	70.0	°F
Actgpm	15.0	gpm
Actcfm	1800	cfm
Fan Power and Heat Correction***		
FanMotor	ECMwFCBlade	
ESP	0.5	in. water
FilterLoss	0.3	in. water
WAEff	30%	
kWFan	0.51	kW
FanHeat	1.7	kBtu/h

Corrected Capacity, Power, EER and COP				
	Pump(s) not Included		Pump(s) Included	
TC	61.6	kBtu/h	61.6	kBtu/h
SC_Est	41.6	kBtu/h	41.6	kBtu/h
SHR	0.68		0.68	
EERnoCF	18.7	Btu/W-h		Btu/W-h
kWc	4.02	kW	4.40	kW
EER	15.3	Btu/W-h	14.0	Btu/W-h
HC	52.0	kBtu/h	52.0	kBtu/h
COPnoCf	4.39	W/W		W/W
kWh	3.95	kW	4.34	kW
COP	3.85	W/W	3.51	W/W
	Optional Pump Power			
	kWpump	0.385	kW	

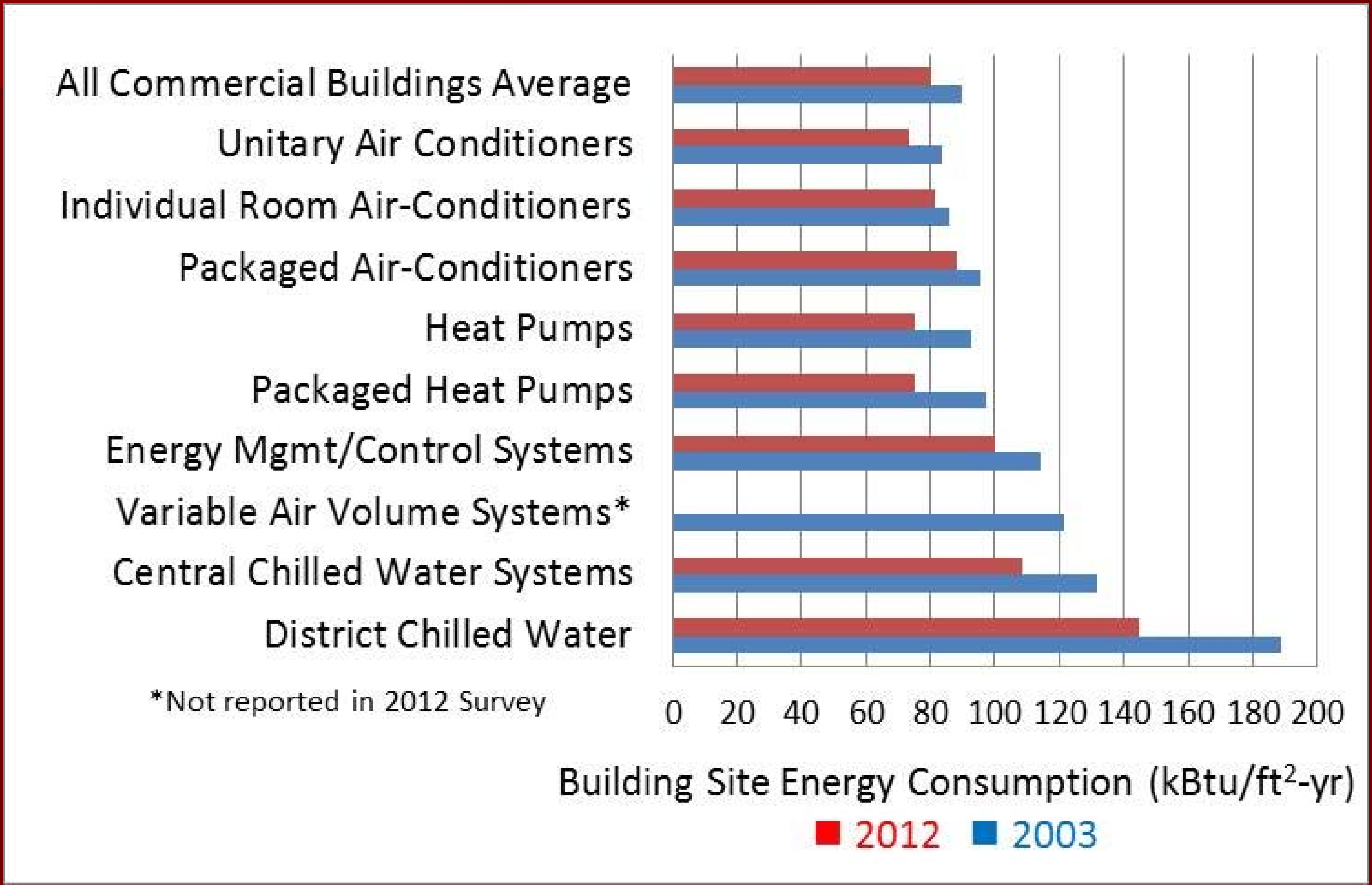
Water-to-Water Heat Pump Performance (I-P)

Based on 53.6°F (12°C) for Cooling and 104°F (40°C) for Heating Building Loop Entering Liquid Temperatures (ELTs)

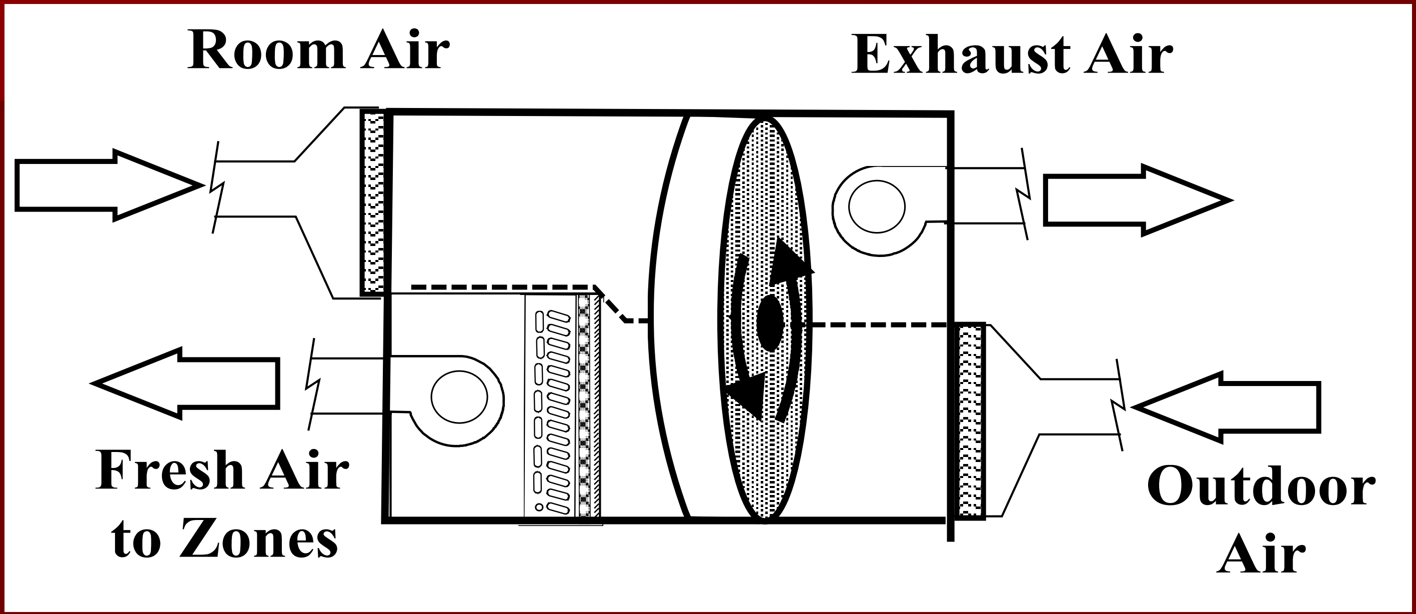
			Water-to-Water Heat Pumps											
	Liquid flows		Water Loop Heat Pump				Ground Water Heat Pump				Ground Loop Heat Pump			
	Source	Bldg.	Clg - 86°F ELT		Htg - 68°F ELT		Clg - 59°F ELT		Htg - 50°F ELT		Clg-77°F (FL)		Htg-32°F (FL)	
Mod	gpm	gpm	TC	EER	HC	COP	TC	EER	HC	COP	TC	EER	HC	COP
96	23	23	93	14.6	125	4.0	105	22.0	103	3.3	100	16.8	82	2.8
108	28	28	103	14.0	142	4.0	123	21.6	118	3.3	114	16.2	93	3.0
120	32	32	128	13.8	175	3.8	151	21.0	145	3.2	139	16.0	115	2.8
140	36	36	143	14.5	193	4.2	166	22.5	160	3.8	155	17.0	127	3.1
180	45	45	170	14.0	209	3.9	183	20.0	189	3.5	177	15.8	153	2.8
210	52	52	202	14.8	257	4.2	227	21.8	219	3.8	212	17.0	173	3.1
240	60	60	222	13.3	286	3.9	257	20.0	244	3.5	242	15.5	193	2.8
360	86	86	335	14.3	453	4.3	na	na	na	na	351	16.2	297	3.2
540	135	135	533	15.2	691	4.3	na	na	na	na	559	16.4	486	3.3
Bldg. Loop: Cooling ELT=53.6°F, Heating ELT= 104°F. TC & HC in Btu/h × 1000, EER in Btu/W-h, COP in W/W														

Correction Factors from Rated Heating Capacity and COP for Other Building Loop ELTs							
ELT = 90°F(32°C)		ELT = 100°F(38°C)		ELT = 110°F(43°C)		ELT = 120°F(49°C)	
HC	COP	HC	COP	HC	COP	HC	COP
1.04	**1.20**	**1.01**	**1.04**	**0.98**	**0.94**	**0.95**	**0.83**

EIA/DOE Commercial Building Energy Consumption Survey (CBECS)—2003 and 2012

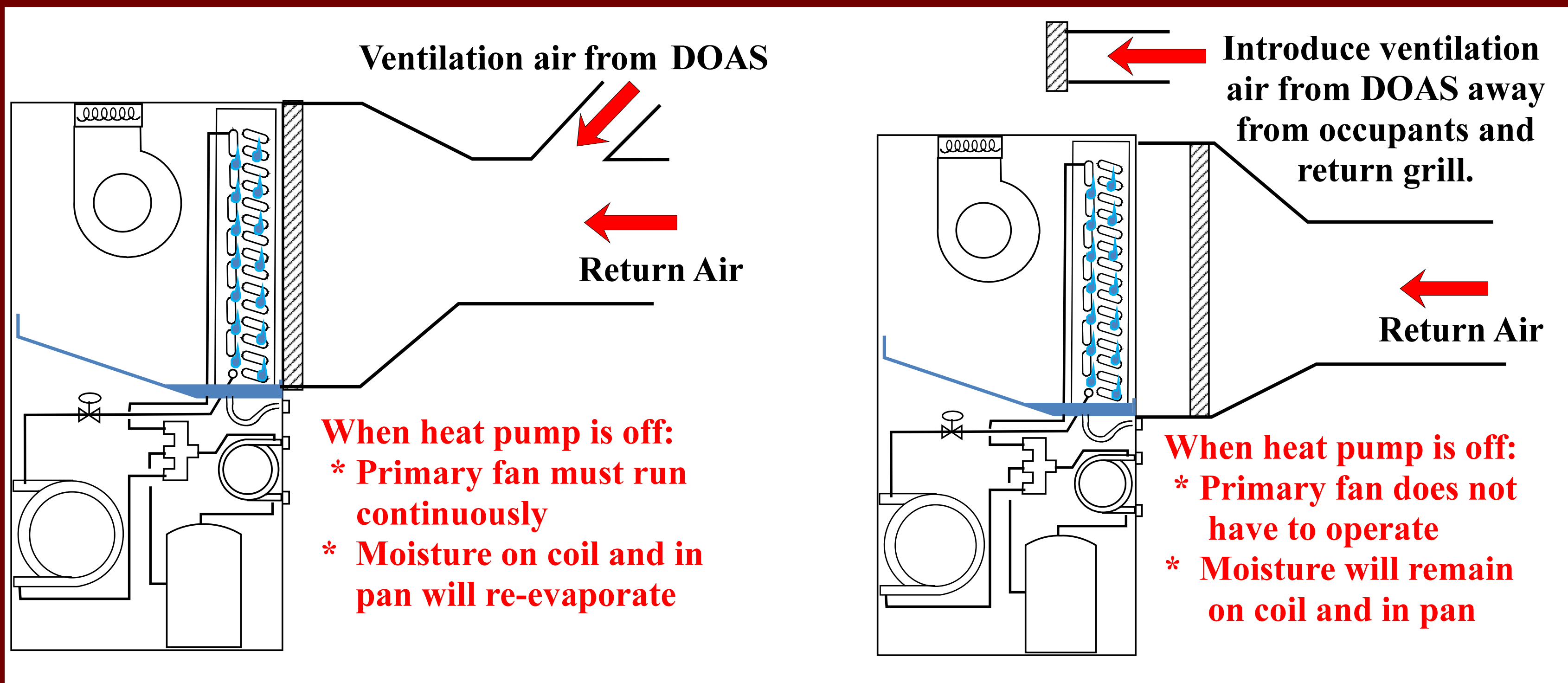


Energy Recovery Unit: An Effective GSHP Loop Reduction Device



But ERUs tend to be more effective in reducing heating requirements than cooling (larger ΔTs and added fan heat). Thus, the annual heat imbalance is further aggravated in applications with equal or greater cooling requirements compared to heating.

Zone Ventilation Air Delivery Options and Issues with Unitary Heat Pumps



Questions?

Comments?

Session 3

APPLIED GCHP DESIGN

Basic Equations

$$q_{cond}/q_{lc} = \frac{EER + 3.412}{EER} = \frac{COP_c + 1.0}{COP_c}$$

The condensing heat rate (q_{cond}) is the heat removed from the building (cooling load = q_{lc}) plus the heat of compression, and is the amount rejected to the ground in cooling.

$$q_{evap}/q_{lh} = \frac{COP_h - 1}{COP_h}$$

Likewise, the evaporating heat rate (q_{evap}) is the heat delivered to the building (heating required = q_{lh}) less the heat of compression, and is the amount removed from the ground in heating.

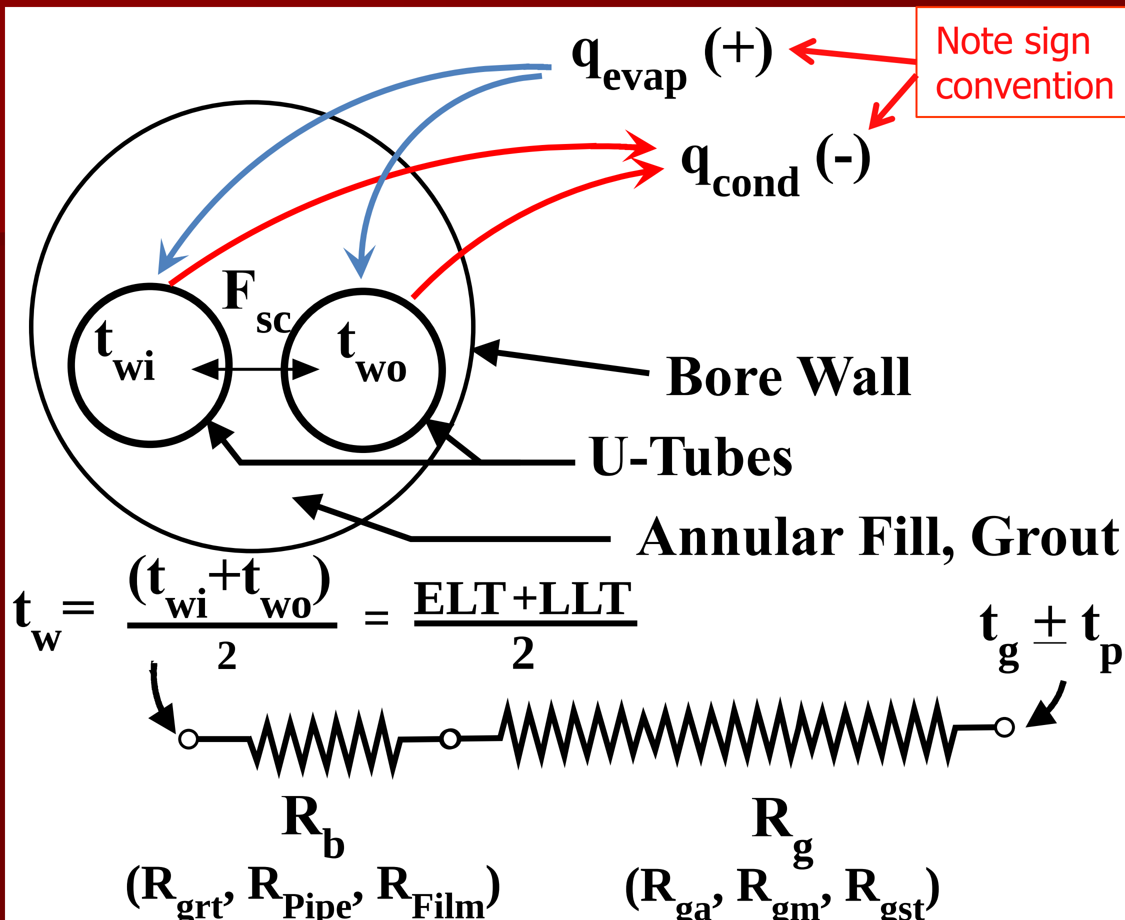
$$q_a = \frac{q_{cond} \times EFLH_c + q_{evap} \times EFLH_h}{8760}$$

The amount of annual heat imbalance to the ground is estimated to account for long-term temperature change by determining the average annual heat rate (q_a).

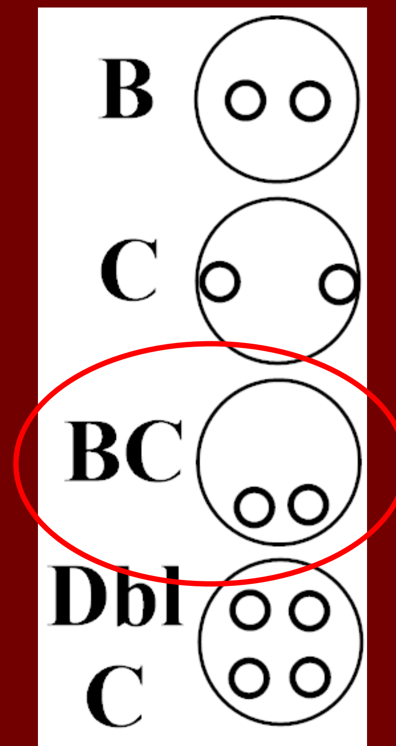
$$L_{bore} = \frac{q \times R_{ov}}{(t_g - t_w)}$$

The total bore length of the vertical ground heat exchanger is determined by multiplying the heat rate (q) by the overall resistance (R_{ov}) divided by the temperature difference between the ground (t_g) and the water in the heat exchanger (t_w).

Overall Bore and Ground Resistance Components



U-tube Locations in Bore



R_b = Bore Resistance
R_b = Grout Resistance
R_b = Grout Resistance
R_b = Boundary Layer Resistance
F_{sc} = U-Tube Short-Circuit Factor

R_g = Ground Resistance
R_g = Annual Ground Resistance
R_g = Monthly Ground Resistance
R_g Short-term Ground Resistance

t_{wi} = Ground Inlet Temperature
t_{wo} = Ground Outlet Temperature
t_g = Undisturbed Ground Temperature
t_p = Long-term Temperature Penalty

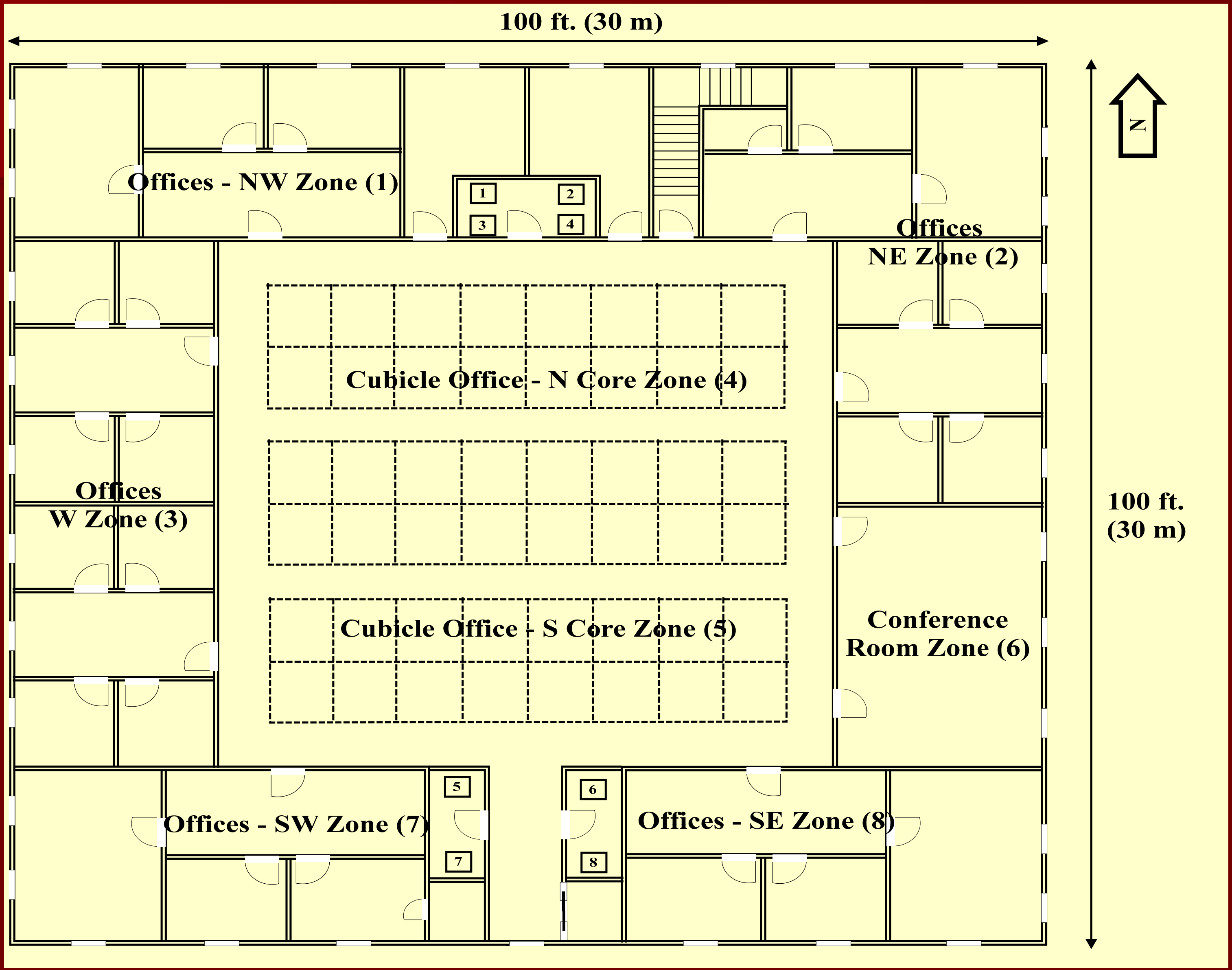
13-Step Design Procedure

1. Calculate cooling load and heat loss
2. Modify building design if loads are high
3. Estimate annual heat imbalance (cooling heat rejection/heating absorption) for potential long-term effects
4. Select preliminary loop operating temperatures
5. Correct equipment rated performance to actual operating conditions
6. Select heat pumps to meet loads—locate units to minimize duct cost, pump energy, and noise
7. Arrange units in circuits (unitary, one pipe, common, central)
8. Determine thermal properties of source—GCHP (TP test), GWHP (well test), SWHP (depth, volume, temperature)

13-Step Design Procedure *(cont.)*

9. Select initial design option: GCHP (bore depth, separation, grout quality, U-tube HEXs per circuit); GWHP (supply well location, separation of injection well, optimum water well flow); SWHPs (length of individual coils, number of coils or plate HEXs per circuit, location in reservoir)
10. Determine optimum heat exchanger dimensions
11. Evaluate other options if initial design unsatisfactory (different loop temperatures, heat pumps, grouts, U-tubes, circuits, bore depths, bore separation, etc.)
12. Lay out exterior and interior piping network and find head loss through critical path and select pumps and calculate grade (A, B, C, D, F) based on pump power/system capacity
13. Calculate ***system*** efficiency (include all equipment) and redesign if efficiency is not superior to conventional HVAC

Example Office Building—St. Louis, MO



Building and Site Conditions—St. Louis

- Indoor temperatures
  - Cooling: 75°F (24°C) dry bulb, 63°F (17°C) wet bulb
  - Heating: 70°F (21°C)
- Outdoor temperatures
  - Cooling (0.4%): 96°F (36°C) dry bulb, 77°F (25°C) wet bulb
  - Heating (99.6%): 6°F (–14°C)
- US Geological Survey maps indicate local deep ground temperature is around 58°F to 59°F

Step 1: Calculate Building Cooling and Heating Requirements

These results obtained with TideLoad15.xlsm, an old fashioned CLTD spreadsheet (but it's free)

		Cooling Loads in kBtu/h				Total Heat Loss in kBtu/h			
	Zn	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am
N. West	1	19.1	28.6	14.9	3.9	20.3	15.8	8.8	10.4
N. East	2	28.6	29.4	15.4	4.8	22.6	17.6	10.4	12.3
West	3	21.3	37.0	22.1	5.1	21.8	17.0	8.3	9.9
N. Core	4	34.2	44.7	11.8	4.7	32.0	24.9	5.3	6.3
S. Core	5	34.2	44.7	11.8	4.7	32.0	24.9	5.3	6.3
Conf	6	35.1	38.3	8.2	4.2	33.3	26.0	5.5	6.5
S.West	7	13.8	21.7	14.2	3.9	13.9	10.8	7.0	8.3
S.East	8	18.3	21.6	13.1	3.9	15.4	12.0	8.2	9.7
Total Building		205	266	112	35	191	149	59	70
		Cooling Loads in kW				Total Heat Loss in kW			
	Zn	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am
N. West	1	5.6	8.4	4.4	1.1	5.9	4.6	2.6	3.0
N. East	2	8.4	8.6	4.5	1.4	6.6	5.2	3.0	3.6
West	3	6.3	10.9	6.5	1.5	6.4	5.0	2.4	2.9
N. Core	4	10.0	13.1	3.5	1.4	9.4	7.3	1.5	1.8
S. Core	5	10.0	13.1	3.5	1.4	9.4	7.3	1.5	1.8
Conf	6	10.3	11.2	2.4	1.2	9.8	7.6	1.6	1.9
S.West	7	4.0	6.4	4.2	1.1	4.1	3.2	2.1	2.4
S.East	8	5.4	6.3	3.8	1.2	4.5	3.5	2.4	2.8
Total Building		60	78	33	10	56	44	17	20

q_{lc} = 266 kBtu/h or 22.2 tons (78 kW)

q_{hc} = 191 kBtu/h (56 kW)

Step 2: Provide Alternatives to Reduce Cooling and Heating Requirements (Add ERU)

		Cooling Loads in kBtu/h				Total Heat Loss in kBtu/h			
	Zn	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am
N. West	1	16.8	25.7	14.9	3.8	15.0	11.7	8.4	10.0
N. East	2	26.3	26.5	15.5	4.7	17.4	13.5	10.0	11.8
West	3	18.4	33.4	22.2	5.1	15.3	11.9	7.9	9.3
N. Core	4	27.2	36.1	11.9	4.6	16.3	12.7	4.2	4.9
S. Core	5	27.2	36.1	11.9	4.6	16.3	12.7	4.2	4.9
Conf	6	27.8	29.3	8.3	4.0	17.0	13.2	4.3	5.1
S.West	7	12.6	20.3	14.3	3.8	11.3	8.8	6.8	8.1
S.East	8	17.1	20.1	13.1	3.9	12.8	10.0	8.0	9.4
Total Building		173	227	112	35	121	95	54	64

		Cooling Loads in kW				Total Heat Loss in kW			
	Zn	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am	8am-Noon	Noon-4pm	4pm-8pm	8pm-8am
N. West	1	4.9	7.5	4.4	1.1	4.4	3.4	2.5	2.9
N. East	2	7.7	7.8	4.5	1.4	5.1	4.0	2.9	3.5
West	3	5.4	9.8	6.5	1.5	4.5	3.5	2.3	2.7
N. Core	4	8.0	10.6	3.5	1.3	4.8	3.7	1.2	1.4
S. Core	5	8.0	10.6	3.5	1.3	4.8	3.7	1.2	1.4
Conf	6	8.2	8.6	2.4	1.2	5.0	3.9	1.3	1.5
S.West	7	3.7	5.9	4.2	1.1	3.3	2.6	2.0	2.4
S.East	8	5.0	5.9	3.9	1.1	3.8	2.9	2.3	2.8
Total Building		51	67	33	10	36	28	16	19

q_{lc} = 227 kBtu/h or 18.9 tons (67 kW)

q_{hc} = 121 kBtu/h (36 kW)

Step 3: Most Folks have a Program that Calculates Off-Peak Loads but Use Estimated PLFs and ASHRAE Equivalent Full Load Hours (EFLH)

Caution is advised in using programs provided by manufacturers because the operating hours often exceed values found in the ASHRAE RP-1120.

Equivalent Full Load Hours (EFLH)

Building Type	Nine to Ten Month Schools		Office – 8 am to 5 pm Five Days / Week		Retail – 8 am to 10 pm Seven Days / Week	
Occupied Hours	**1300 - 1500**		**2200 - 2400**		**2800 - 3600**	
Location	Cooling	Heating	Cooling	Heating	Cooling	Heating
Atlanta	590-830	200-290	950-1360	480-690	1300-1860	380-600
Baltimore	410-610	320-460	690-1080	720-890	880-1480	570-770
Bismarck	150-250	460-500	250-540	950-990	340-780	810-900
Boston	300-510	450-520	450-970	960-1000	610-1380	760-870
Charleston, WV	430-570	310-440	620-1140	770-840	820-1600	620-730
Charlotte	510-730	200-320	940-1340	530-780	1280-1830	420-670
Chicago	280-410	390-470	420-780	820-920	550-1090	670-810
Dallas	620-890	120-200	1100-1580	340-520	1460-2090	280-440
Detroit	230-360	400-480	390-820	970-1020	530-1170	790-900
Fairbanks, AK	25-50	560-630	60-200	1050-1170	110-320	930-1090
Great Falls, MT	130-220	360-430	210-490	820-890	290-710	680-800
Hilo, HI	970-1390	0	1800-2580	15-25	2260-3370	0-20
Houston	670-1000	90-130	1240-1770	250-350	1600-2290	190-300
Indianapolis	380-560	400-480	560-1000	840-920	730-1410	690-820
Los Angeles	610-910	80-160	1140-1670	370-580	1650-2350	250-440
Louisville	470-670	290-430	770-1250	710-830	1000-1720	570-720
Madison	210-310	390-470	320-640	840-900	420-900	700-800
Memphis	580-830	170-240	950-1350	420-600	1250-1780	330-510
Miami	950-1300	10	1500-2150	35-45	1920-2740	25-40
Minneapolis	200-300	420-500	320-610	860-950	430-870	720-860
Montgomery	630-910	120-180	1060-1510	330-470	1390-1990	250-400
Nashville	520-740	250-320	830-1280	590-680	1030-1710	470-590
New Orleans	690-990	70-110	1200-1720	230-320	1570-2240	160-260
New York	360-550	350-440	540-1040	790-870	720-1480	630-760
Omaha	310-440	330-400	480-820	720-800	610-1130	600-720
Phoenix	710-1020	70-110	1130-1610	210-290	1430-2090	170-250
Pittsburgh	300-530	470-500	440-920	910-950	600-1310	750-840
Portland, ME	190-300	400-480	310-630	880-980	410-900	710-870
Richmond, VA	510-730	270-410	880-1310	660-820	1110-1770	520-710
Sacramento	600-850	220-360	1000-1430	640-990	1390-2020	480-830
Salt Lake City	410-710	520-540	510-1090	1040-1060	660-1520	830-930
Seattle	260-460	460-650	440-1200	1270-1370	710-1860	960-1170
St. Louis	390-550	280-400	680-1100	710-800	850-1500	570-700
Tampa	780-1110	40-60	1440-2000	140-190	1780-2560	100-160
Tulsa	540-770	240-300	830-1300	560-620	1030-1730	450-540

Step 4: Loop Operating Temperature and Liquid Flow Rates to Optimize Performance/First-Cost Trade-Off

- In cooling temperature entering heat pump (ELT) = 20°F to 30°F (11°C to 17°C) above the normal deep ground temperature (t_g).
- In heating temperature entering heat pump (ELT) = 10°F to 15°F (6°C to 8°C) below the normal deep ground temperature (t_g).
- Liquid flow rates 2.5 to 3.0 gpm/ton (2.7 to 3.2 Lpm/kW)

Step 5: WAHP Performance Correction (Free)

(Other options: manual calculations or shortcut method from Session 2)

Rated Performance

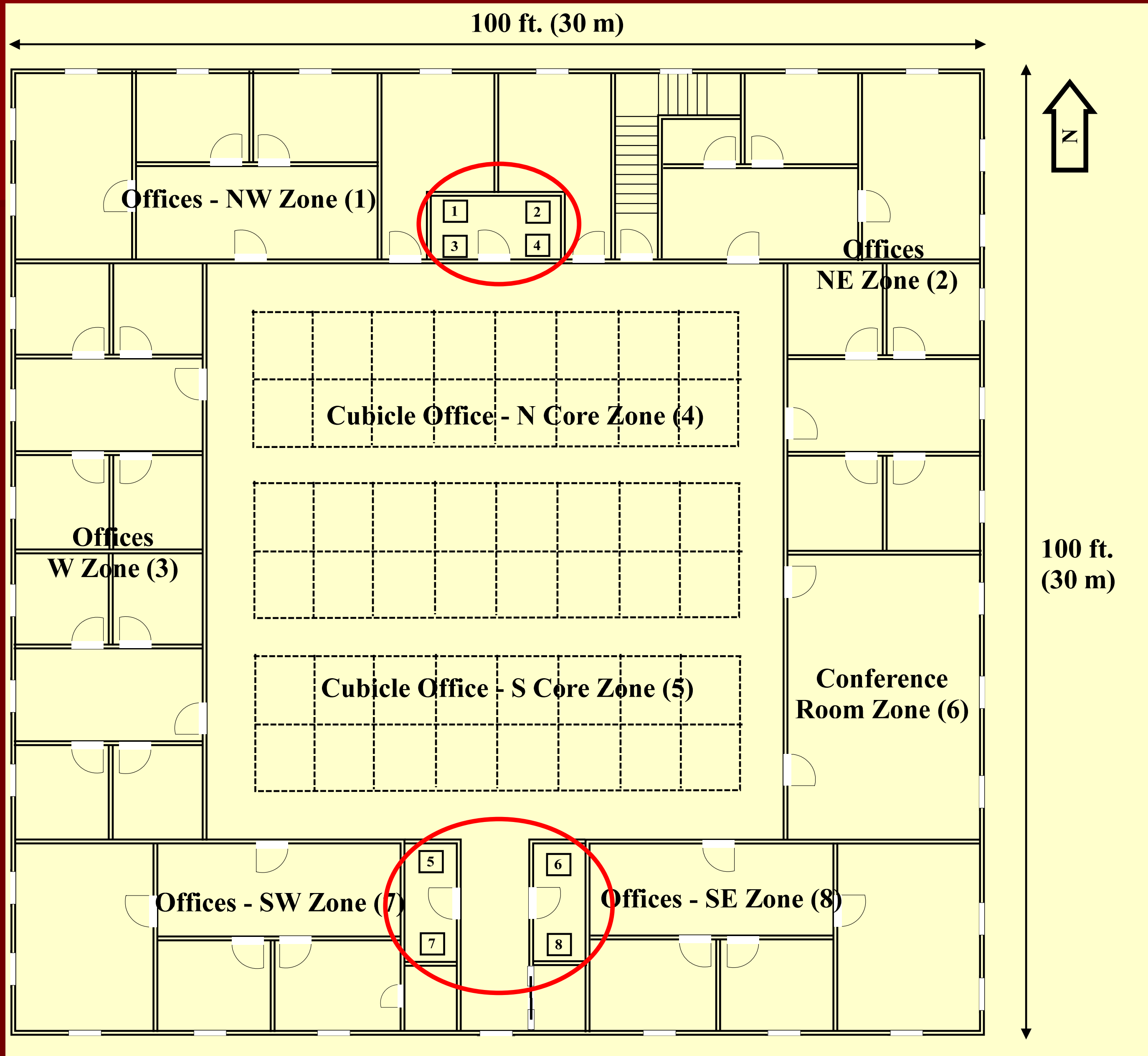
HC32	COP32	HC50	COP50	HC68	COP68
43.3	3.9	55.1	4.7	69.8	5.4

gpm	cfm	TC59	EER59	TC77	SC77	EER77	TC86	EER86
15	1800	72.0	26.1	66.8		19.5	64.3	17.2

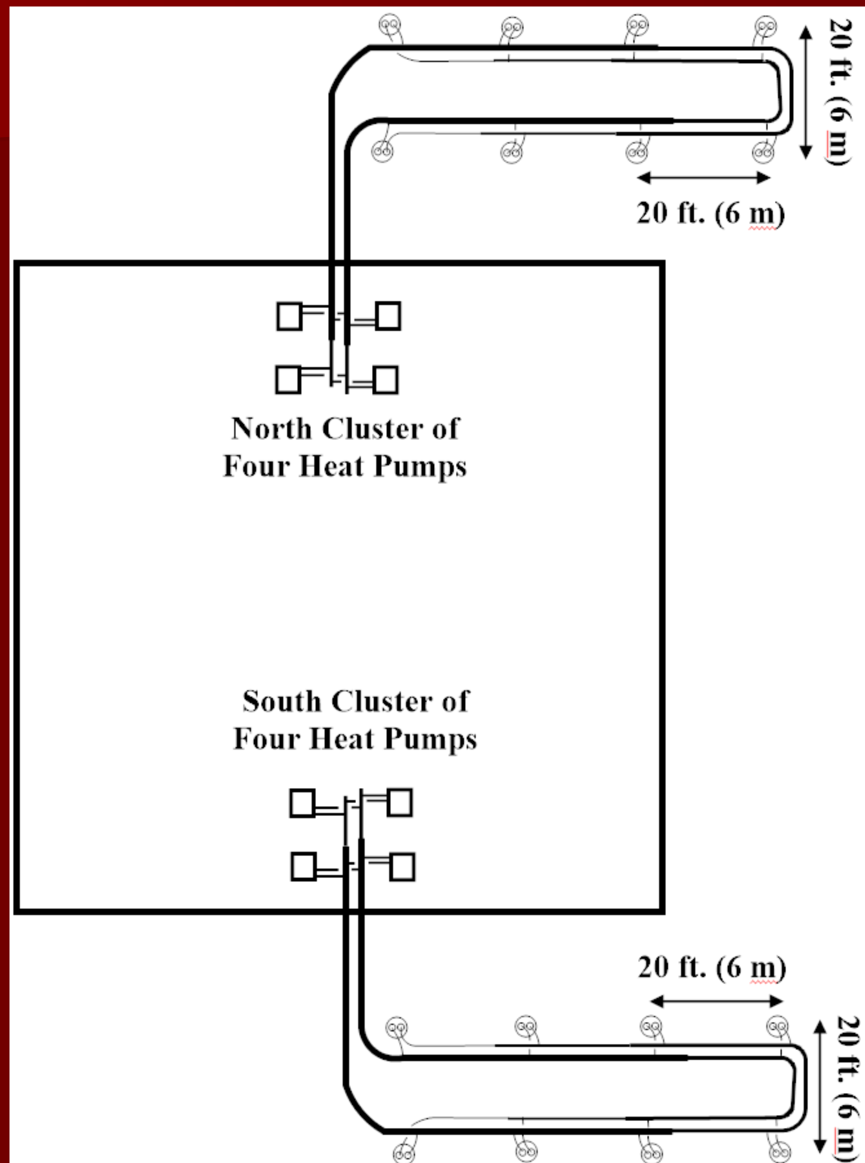
Corrected Performance (includes fan and pump power, fan heat)

GLHP Rated Performance				Operating Conditions			Corrected Capacity, Power, EER and COP				
Model#	ECM-60			ELTClg	80.0	°F		Pump(s) not Included		Pump(s) Included	
TC-77°F	66.8	kBtu/h		ELTHtg	43.0	°F	TC	61.6	kBtu/h	61.6	kBtu/h
SC-77°F	0	kBtu/h		EATdbClg	75.0	°F	SC_Est	41.6	kBtu/h	41.6	kBtu/h
EER-77°F	19.5	Btu/W-h		EATwbClg	63.0	°F	SHR	0.68		0.68	
HC-32°F	43.3	kBtu/h		EATHtg	70.0	°F	EERnoCF	18.7	Btu/W-h		Btu/W-h
COP-32°F	3.9	W/W		Actgpm	15.0	gpm	kWc	4.02	kW	4.40	kW
WtrFlow	15.0	gpm		Actcfm	1800	cfm	**EER**	15.3	Btu/W-h	14.0	Btu/W-h
AirFlow	1800	cfm		Fan Power and Heat Correction***			HC	52.0	kBtu/h	52.0	kBtu/h
GpmPTonR	2.7			FanMotor	ECMwFCBlade		COPnoCf	4.39	W/W		W/W
CfmPTonR	323			ESP	0.5	in. water	kWh	3.95	kW	4.34	kW
GpmPTonA	2.7			FilterLoss	0.3	in. water	**COP**	3.85	W/W	3.51	W/W
				WAEff	30%						
				kWFan	0.51	kW		Optional Pump Power			
				FanHeat	1.7	kBtu/h		kWpump	0.385	kW	

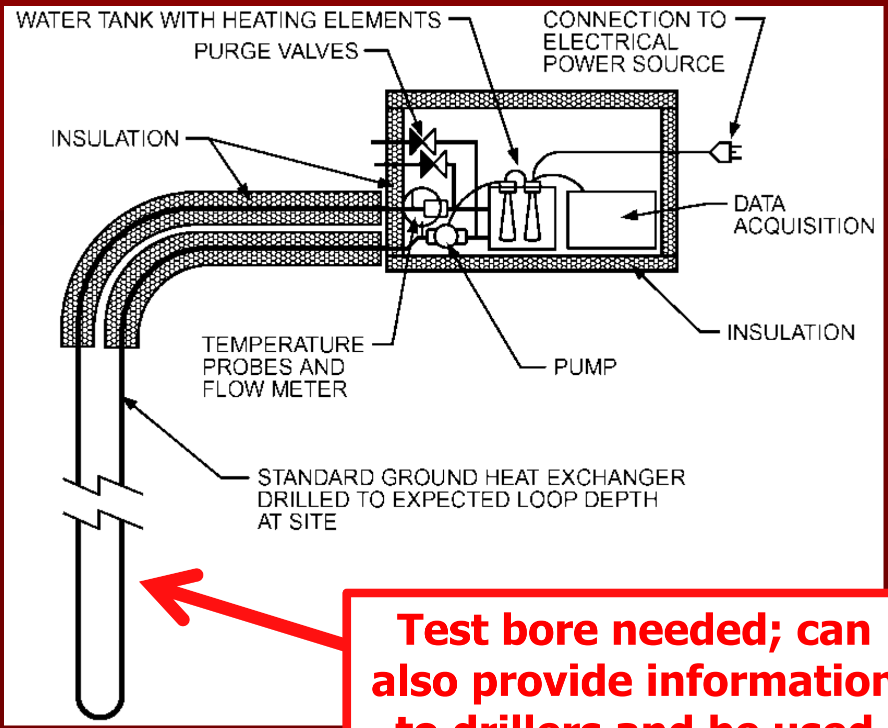
Step 6: Select and Locate Heat Pumps



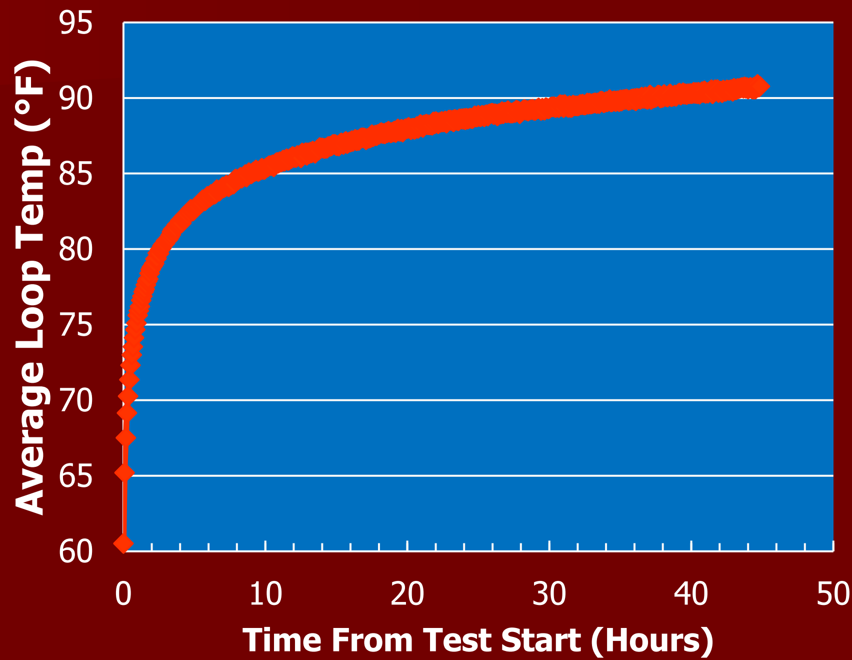
Step 7: Arrange Heat Pumps in Ground Loop Circuits
Initial Design: Two Common Loops with Four Heat Pumps Each



Step 8: Thermal Property (TP*) Test Equipment



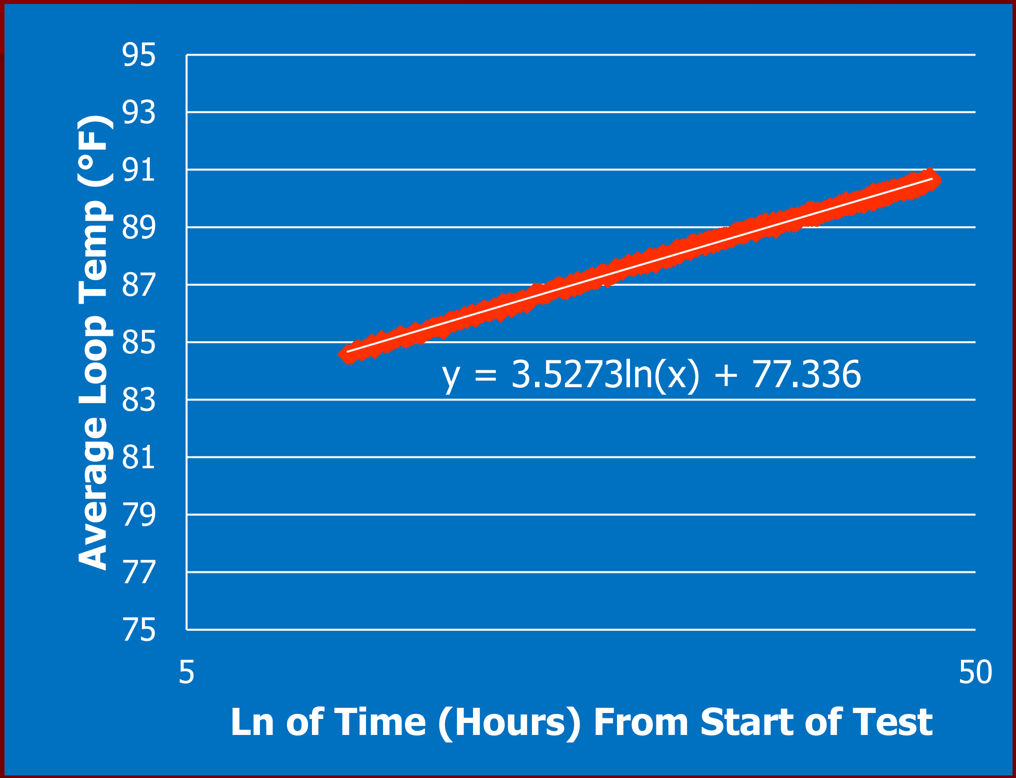
Test bore needed; can also provide information to drillers and be used as part of building loop after TP test is completed.



Natural ground temperature (t_g) found at start of test before heating elements are activated

*Often called a *thermal conductivity (TC)* test, but natural ground temperature (t_g) and thermal diffusivity (α_g) needed

Step 8: TP Test Results Converted to Natural Log of Time Versus Average Temperature to Determine Ground Thermal Conductivity (k_g)



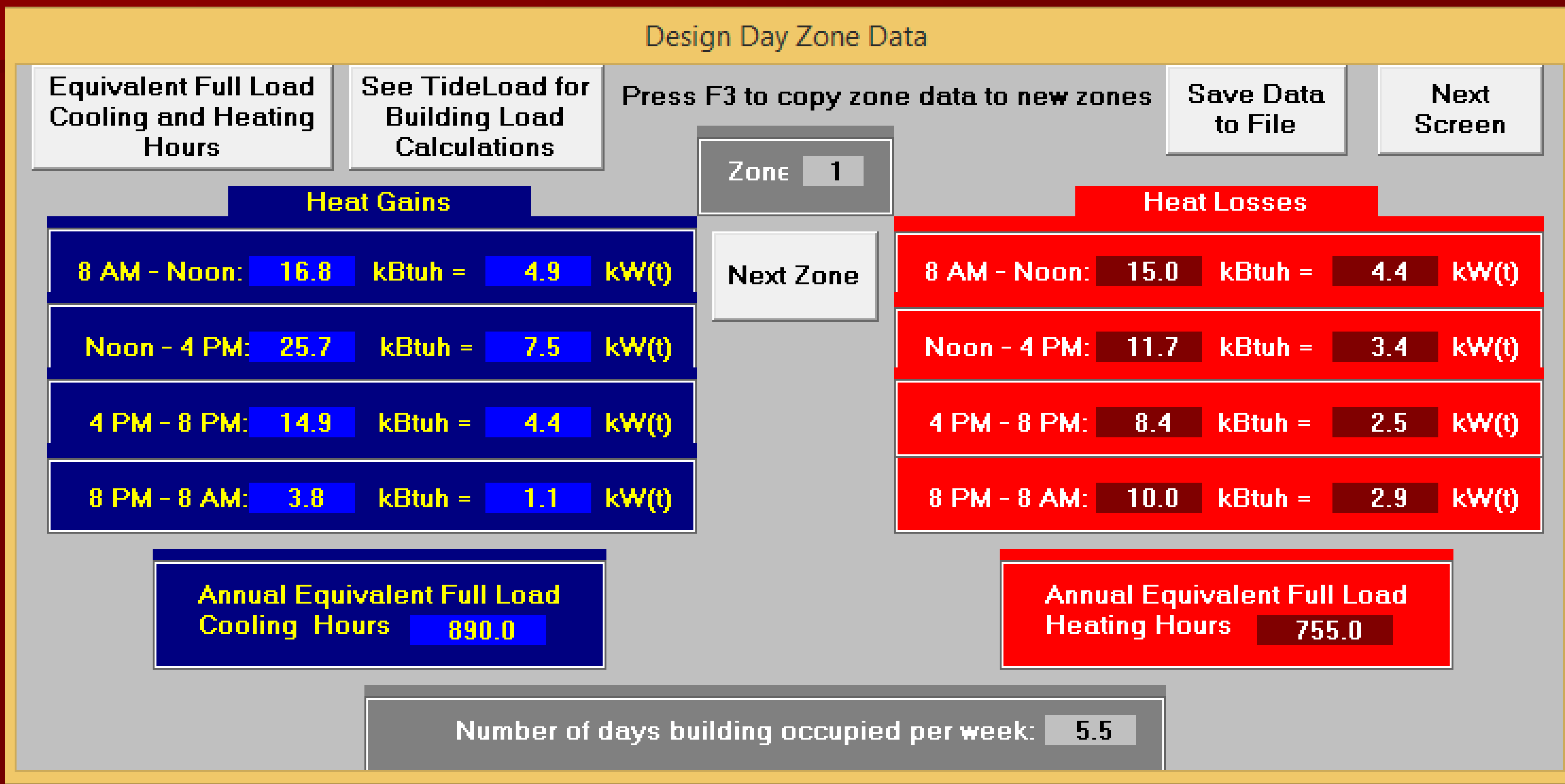
Avg. Temperature vs. Ln (Time)

$$kg = \frac{3.412\frac{Btu}{W\cdot h}\times W}{4\pi L_{bore}\times Slope} = \frac{3.412\frac{Btu}{W\cdot h}\times 5060\,W}{4\pi\times 300(ft.)\times 3.5273°F} = 1.30\,\frac{Btu}{h\text{–}ft\text{–}°F} = 2.25\,\frac{W}{m\text{–}K}$$

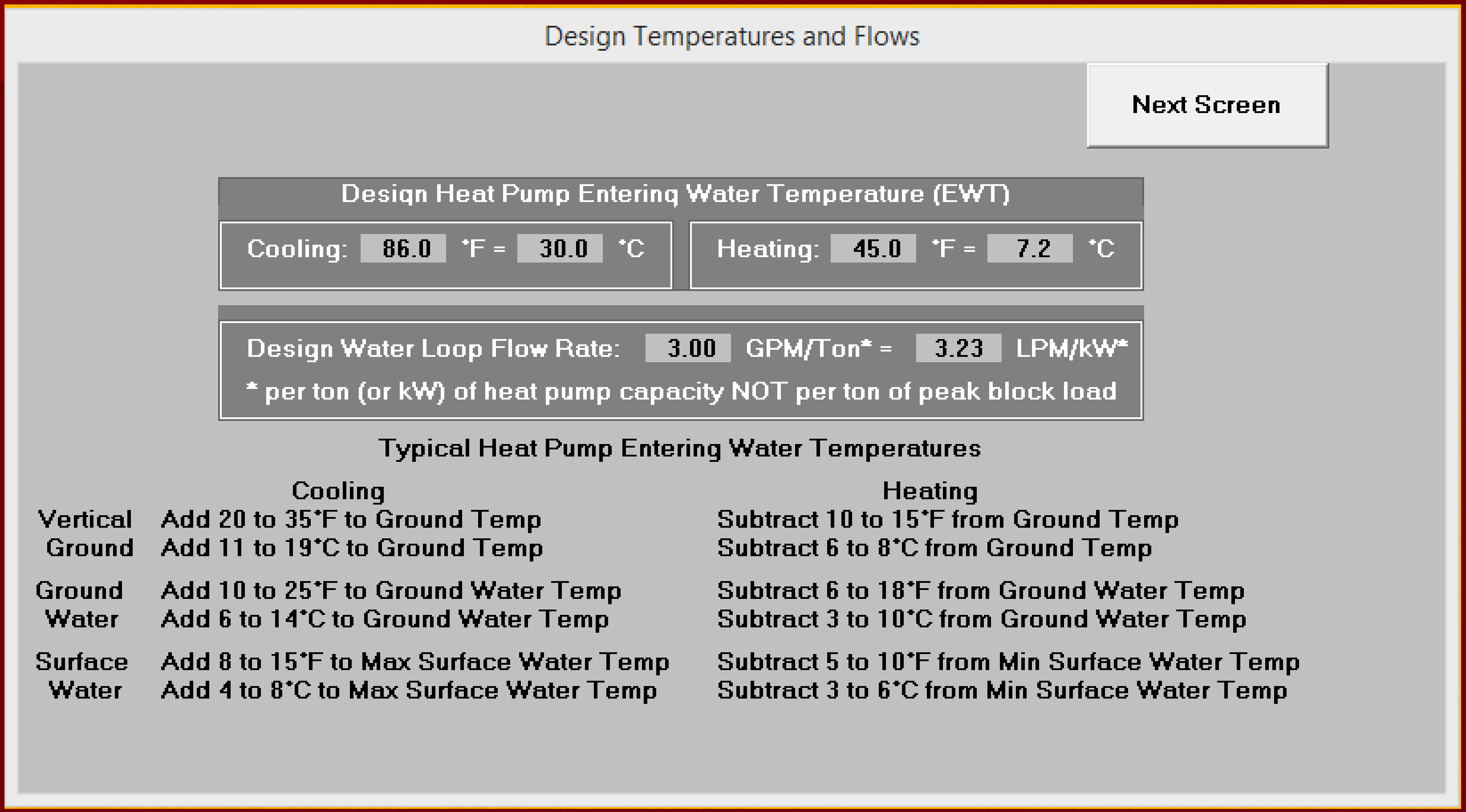
Note:

Previous versions of this seminar detailed hand calculation procedures for system design. This proved difficult to complete during a three-hour seminar. The following slides are taken from a free computer program (GshpCalc) based on the calculations. Attendees wishing to receive copies of the hand calculations or the computer program may find them on the same site as the downloadable course materials for this course. Additional instructions on Slide 132.

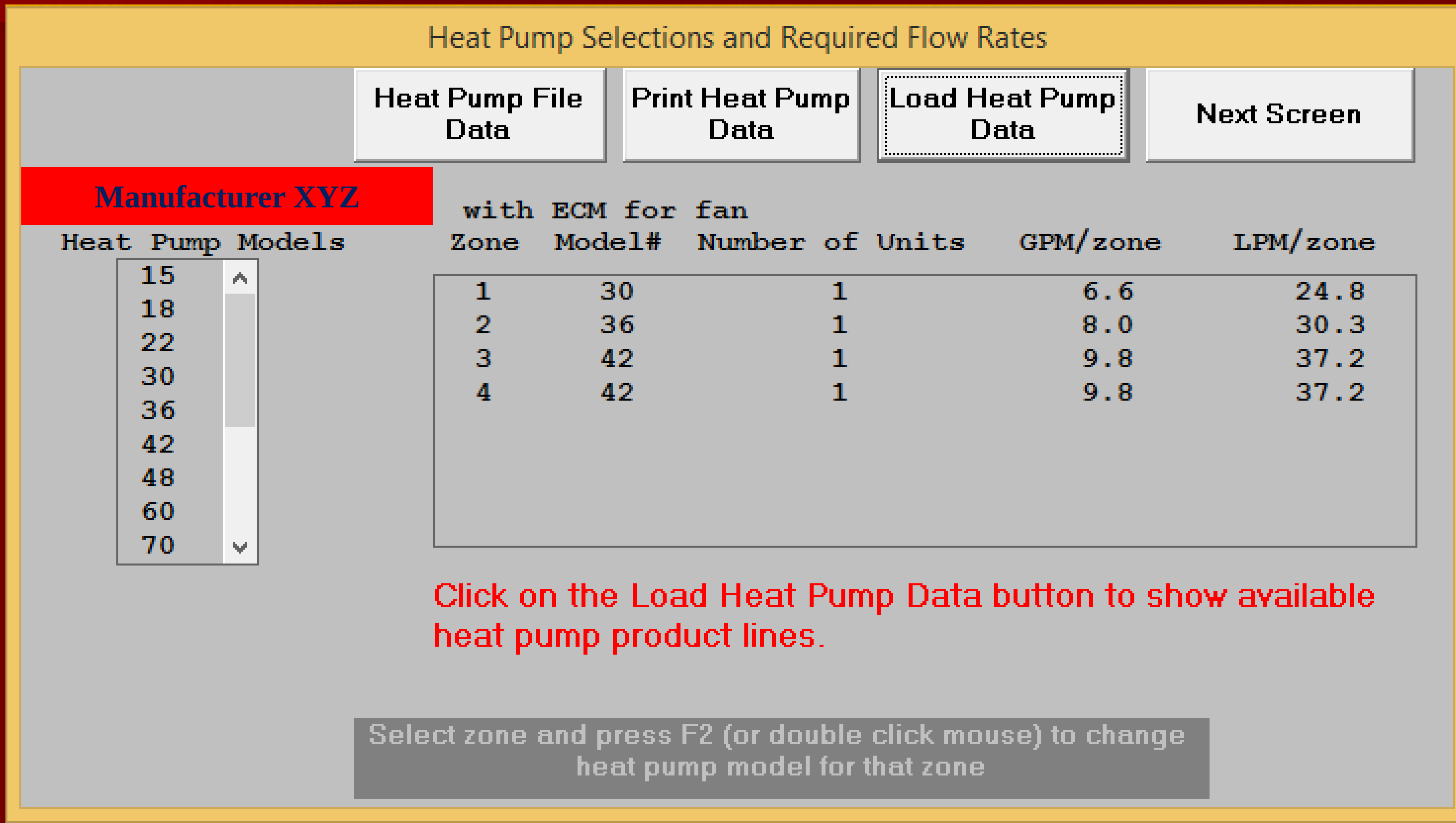
Steps 1, 2, and 3: Enter Zone Load Calculation Results , Optimize if Values High , and Enter EFLHours



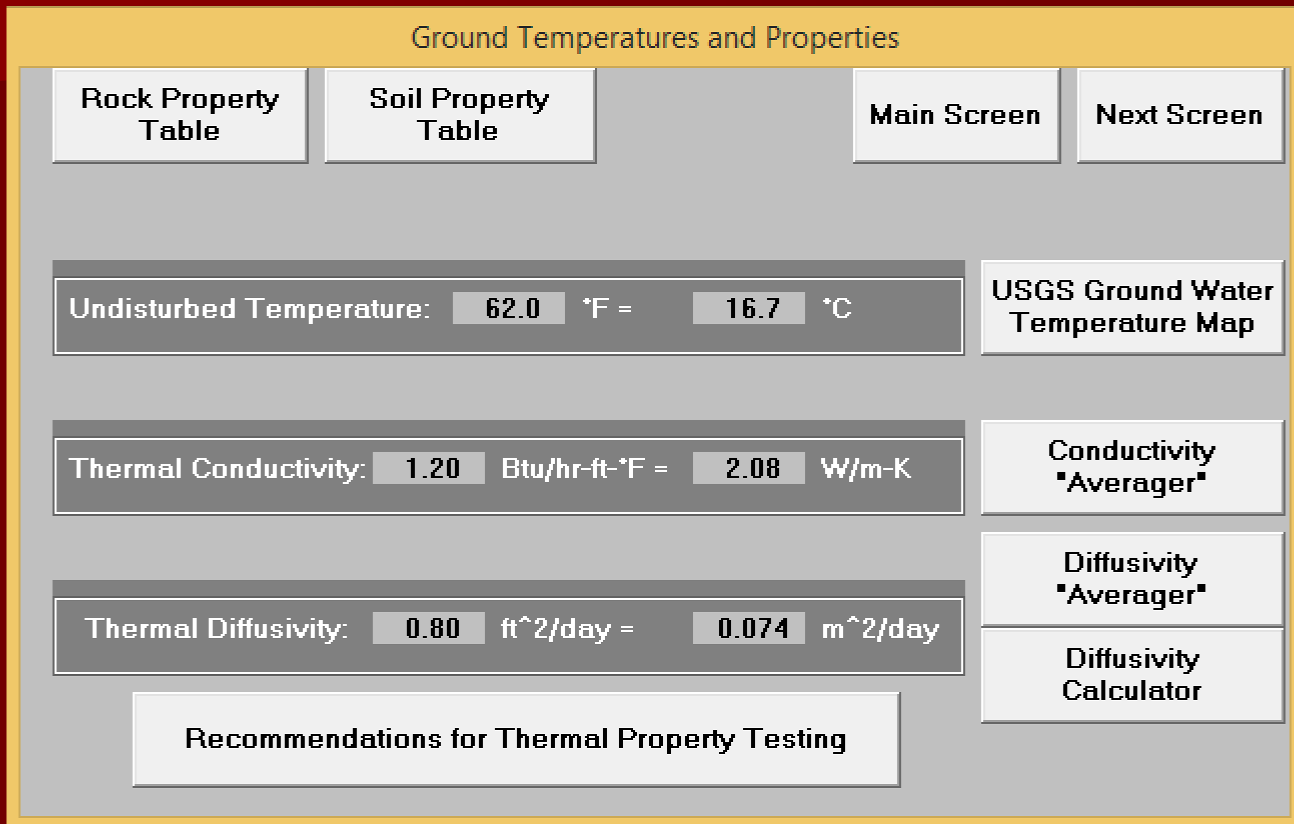
Step 4 Select Loop Operating Temperatures and Flow Rates



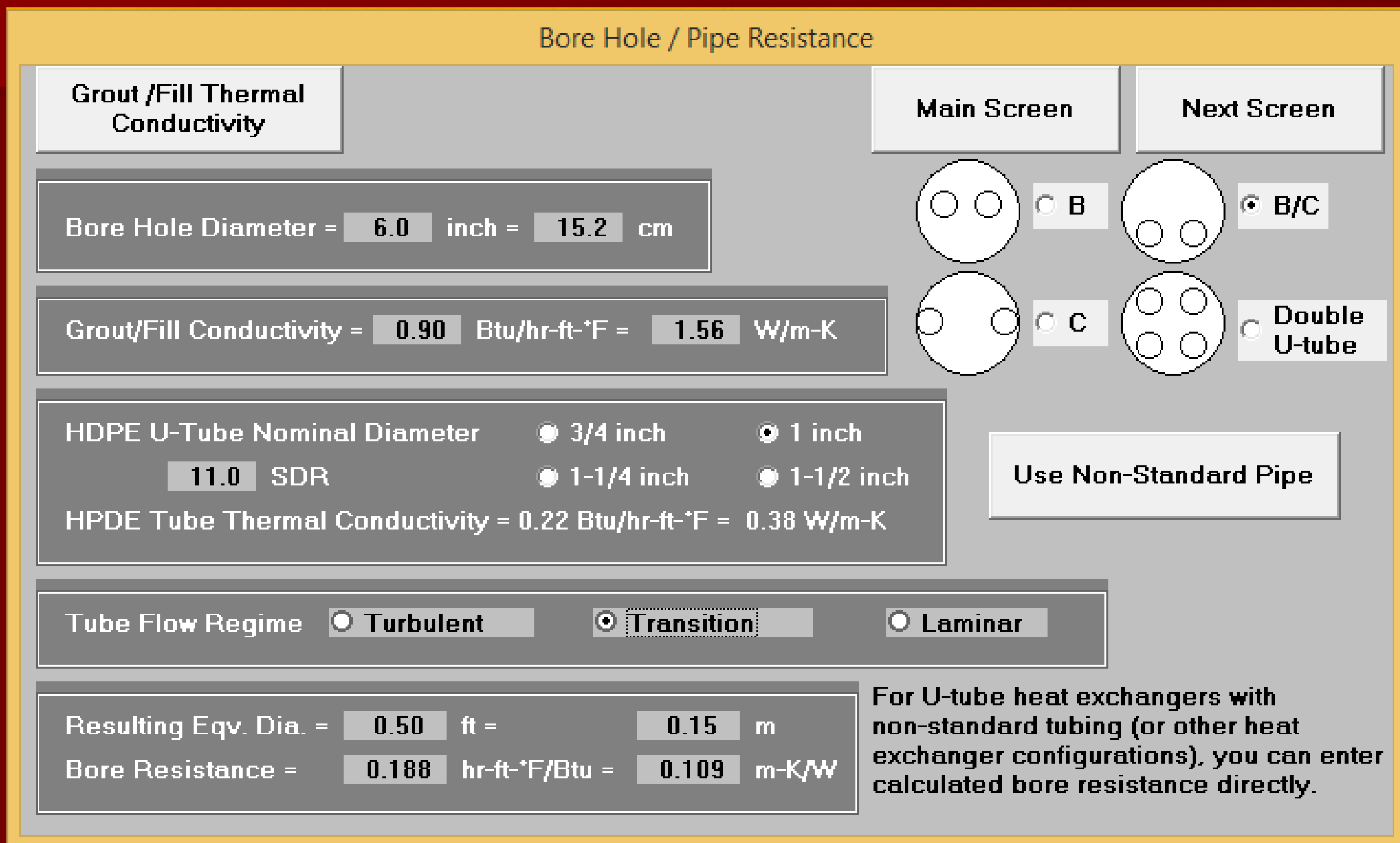
Step 5 Select Heat Pump Manufacturer (from a List) and Correct Performance to Water and Air Conditions (Done Automatically)



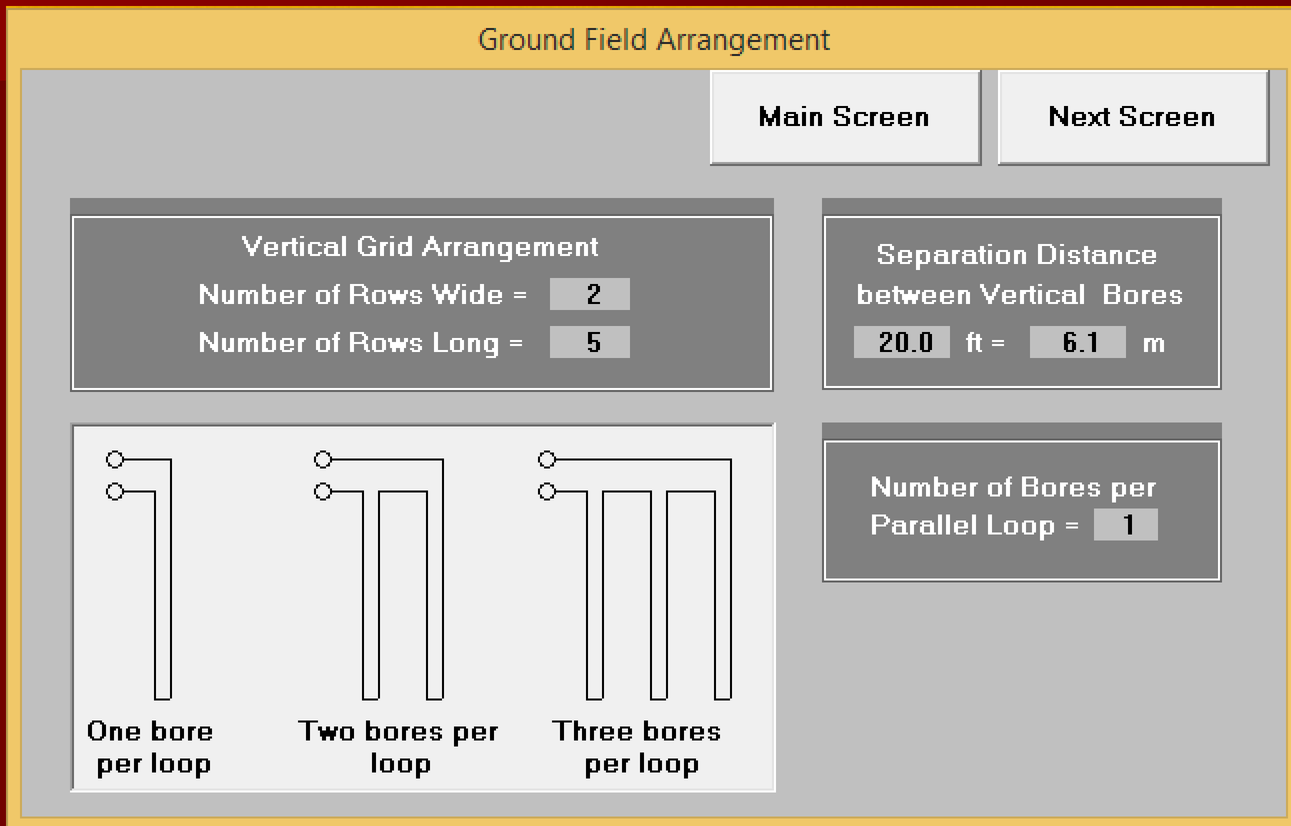
Step 8 Enter Ground Thermal Properties (Steps 6 and 7, See Previous Slides 64 and 65)



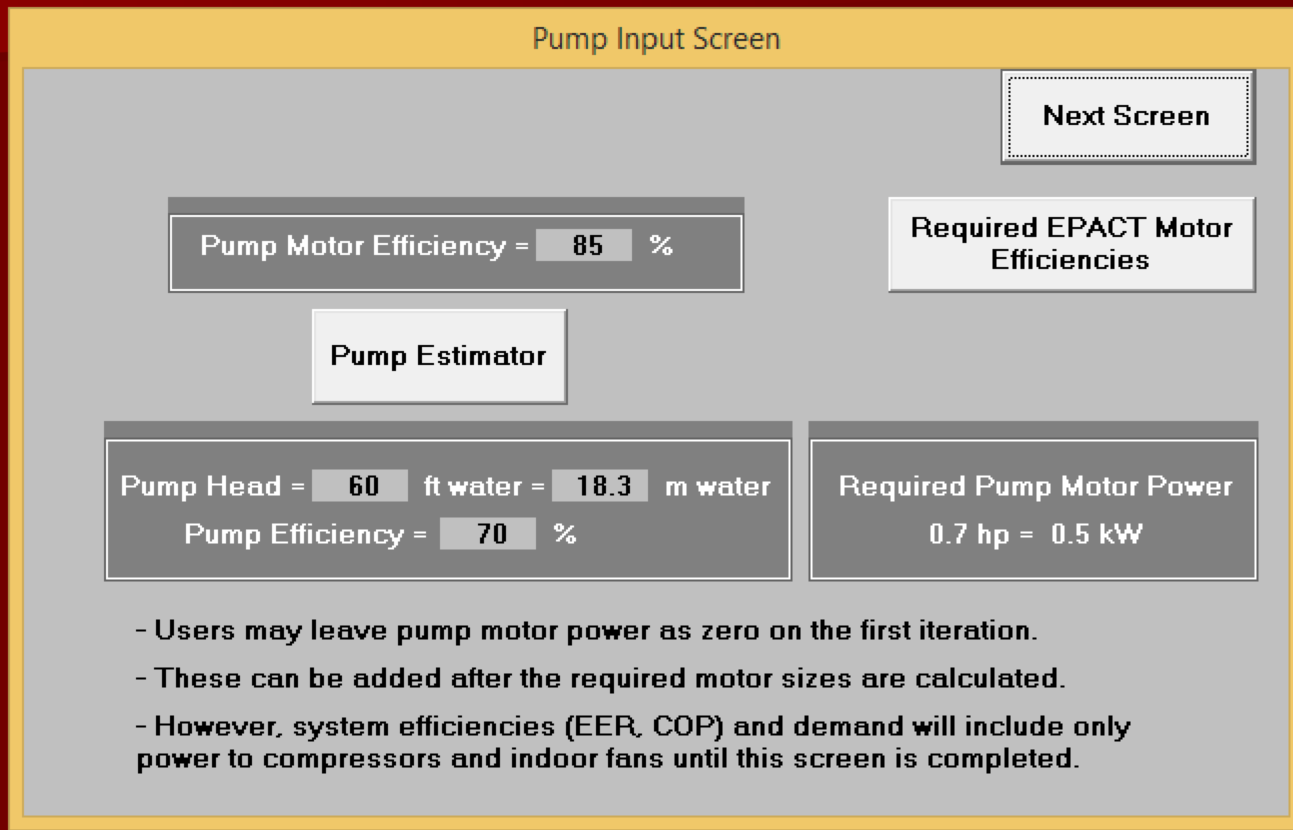
Step 9 Select Ground Heat Exchanger Specifications



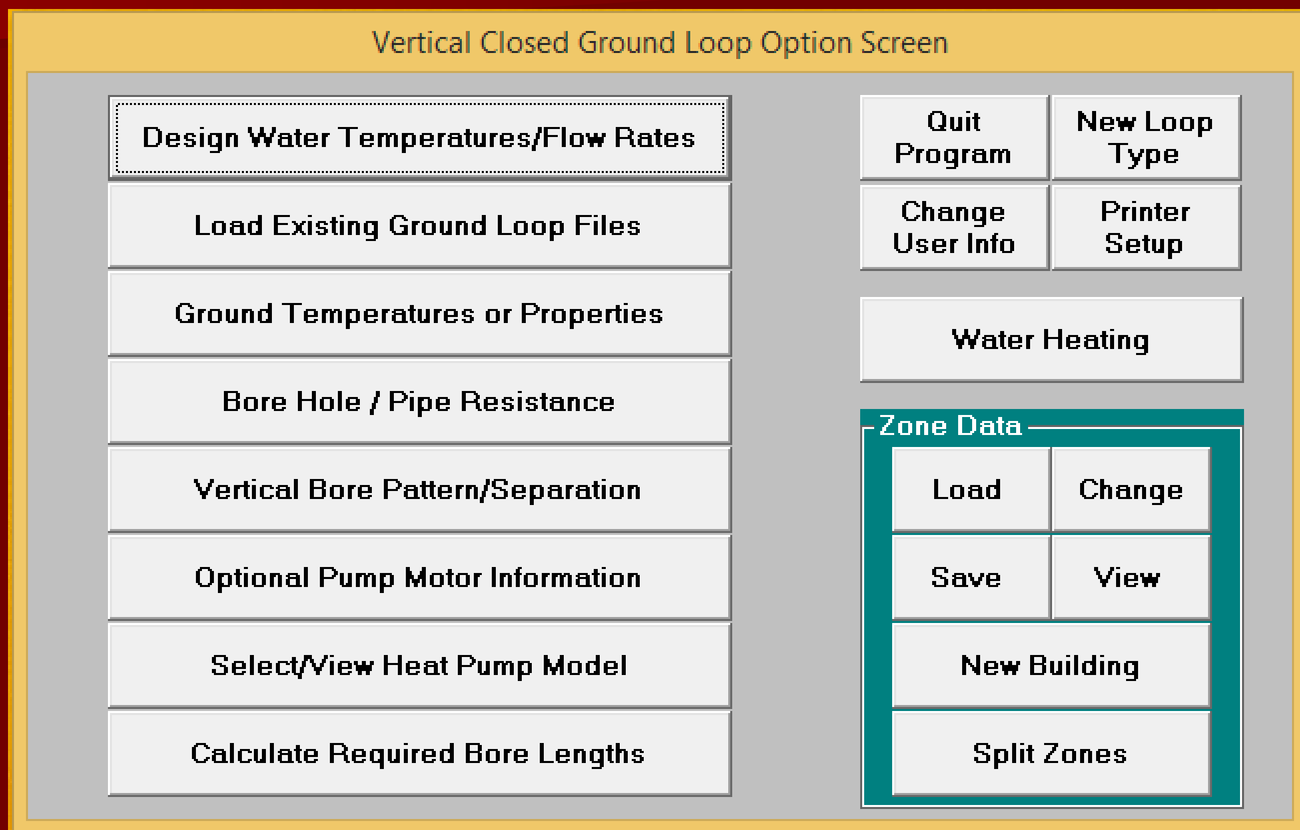
Step 9 Continued Select Ground Heat Exchanger Specifications



Preliminary Step 12 Specify Pump (to Include in System Heat Balance Calculations)



Options Screen to Complete Initial Design or Make Changes



Steps 10, 11, and 13* Complete Initial Design and Calculate System Efficiency

Vertical Closed Ground Loop Design Lengths - U.S Units

Design Hybrid GCHP | Long Term Temps | Save Input to File | Metric Units | Print Values | Next Screen

Required BORE length with minimal groundwater movement = 2350 ft (236 ft/bore)
(Design based on COOLING mode - net annual heat rejection to ground)

Required BORE lengths with high rates of groundwater movement (or year 1)
Cooling: L= 2190 ft (220 ft/bore), Heating: L= 2150 ft (215 ft/bore)

*** Heat Pump Series: WaterFurnace Envision with ECM for fan ***

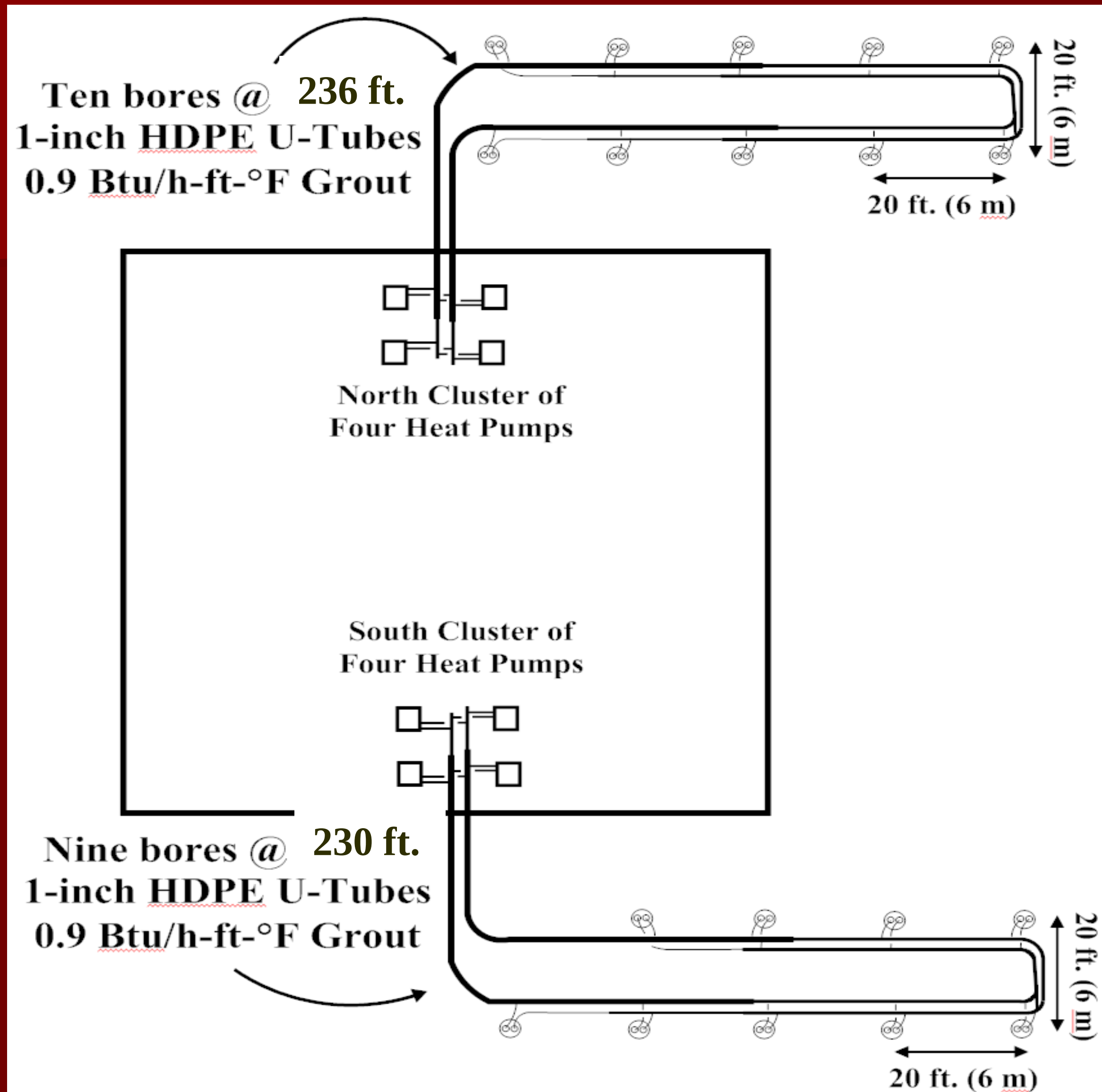
Temperatures
Unit Inlet (cooling) = 86.0°F
Unit Outlet (cooling) = 95.6°F
Unit Inlet (heating) = 55.0°F
Unit Outlet (heating) = 48.6°F
Normal ground temp = 62.0°F

Maximum Block Loads/Demands
Cooling Load/Demand = 122 kBtuh / 7 kW
Heating Load/Demand = 64 kBtuh / 4 kW
Cooling EER (Ht Pump/Sys) = 16.6 / 15.4
Heating COP (Ht Pump/Sys) = 5.0 / 4.3
Loop Pump Head/Flow Rate = 60 ft / 30 gpm
Loop Pump Power/Demand = 0.7 hp / 0.6 kW

U-bend/Bore Data
U-tube Diameter = 1.00 inch
Separation dist. = 20.0 ft
Grid = 2 wide by 5 deep
Grout Conductivity = 0.90 Btu/hr-ft-°F
Bore Diameter = 6.00 inches

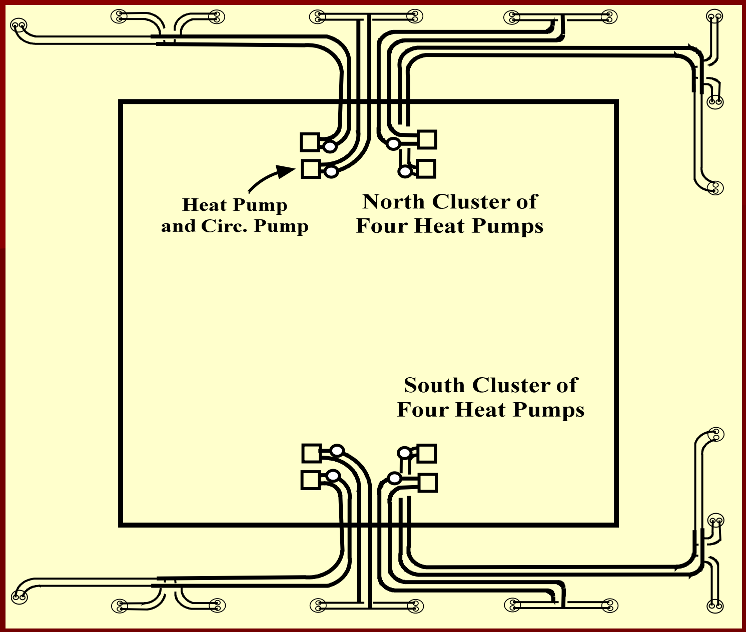
Ground Data
Thermal Conductivity = 1.20 Btu/hr-ft-°F
Thermal Diffusivity = 0.80 ft^2/day
Ground Temperature = 62.0 °F

*Details of Step 12 (Calculate system head loss and specify pump(s) addressed in next session.

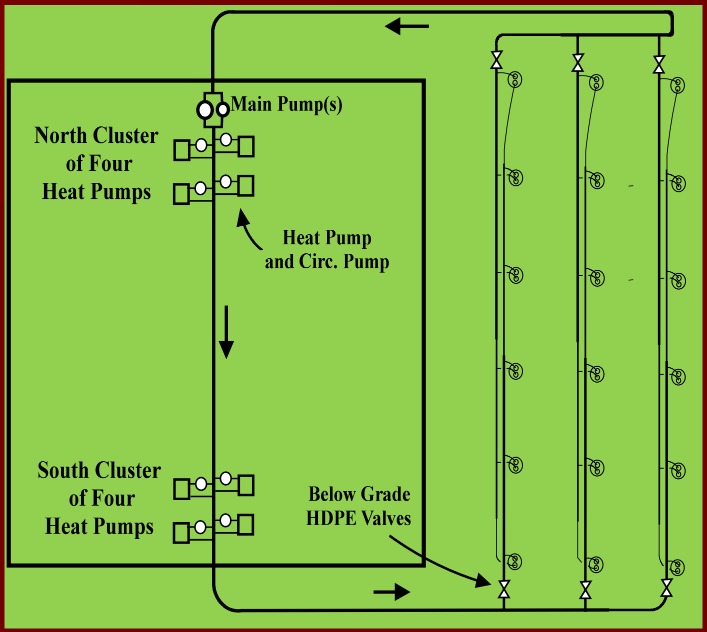

Ten bores @ 236 ft.
1-inch HDPE U-Tubes
0.9 Btu/h-ft-°F Grout
20 ft. (6 m)
20 ft. (6 m)
North Cluster of
Four Heat Pumps
South Cluster of
Four Heat Pumps
Nine bores @ 230 ft.
1-inch HDPE U-Tubes
0.9 Btu/h-ft-°F Grout
20 ft. (6 m)
20 ft. (6 m)

Alternative Designs—Step 11

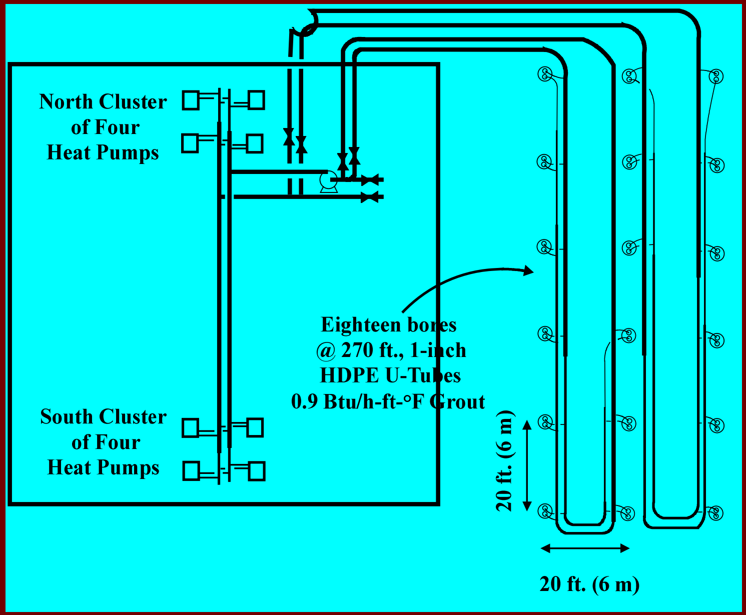
Unitary Loops



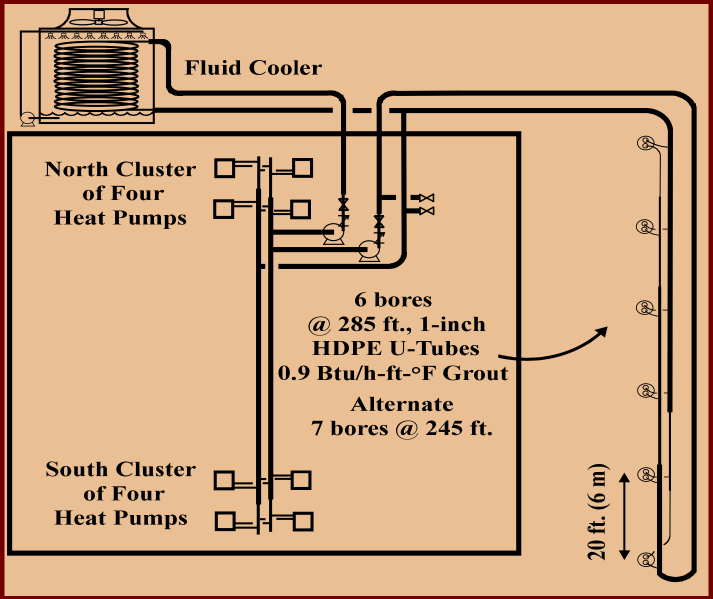
One-Pipe Loop



Central Loop



Hybrid System



Summary of Alternatives

Original Design: System EER = 13.9, COP = 4.0, ELT(clg) = 86°F (30°C), ELT(htg) = 50°F (10°C), nineteen vertical bores at 4800 ft (1460 m) total, 1-inch nominal (32 mm) HDPE U-tubes, 20 ft. (6 m) bore separation, two ground loop circuits (10 bore and 9 bore), 0.90 Btu/h-ft-°F (1.56 W/m-K) grout conductivity, eight 200-W pumps, on-off controls with check valves.			
Design alternative	Ground loop size	Efficiency	Other
Eight unitary loop	No change	1% Increase	Check valves no longer required
One-pipe loop 1.5-hp (1.1 kW) & 12 circulator pumps	1% Increase	1% Decrease	Central pump(s) added
Central loop with single 2-hp (1.5 kW) pump	1% Increase	No change	2-way heat pump valves , VS pump
Increase grout conductivity to 1.5 Btu/h-ft-°F	9.3% Decrease	No change	Higher material cost
Use double U-tubes in vertical bores	12.6% Decrease	No change	Addition header fittings required
Double U-tubes + 1.5 Btu/h-ft-°F grout	17.8% Decrease	No change	Addition header fittings required
Double U-tube conductivity (to 0.44 Btu/h-ft-°F)	12.6% Decrease	No change	Higher material cost
Double U-tube cond. + 1.5 Btu/h-ft-°F grout	14.4% Decrease	No change	Much higher material cost
Reduce grout conductivity to 0.42 Btu/h-ft-°F	23% Increase	No change	Grout mat'l weight reduced 400%
Increase bore separation distance to 25 ft. (7.6 m)	8 to 12% Decrease	No change	Increase in req'd ground area by 56%
Decrease bore separation distance to 15 ft. (4.6 m)	21 to 44% Increase	No change	Increased possiblity of cross-drilling
Increase ELT(clg) to 95°F (35°C)	20% Decrease	13% Decrease	Heat pumps only rated to ELT = 86°F
Decrease ELT(clg) to 77°F (25°C)	38% Increase	9% Increase	Much higher ground loop cost
Hybrid-System (fluid cooler)	60% Decrease	9% Decrease	Much higher maintenance cost
Copper U-tubes and 5.0 Btu/h-ft-°F grout	21% Decrease	No change	Much higher cost, grout not available

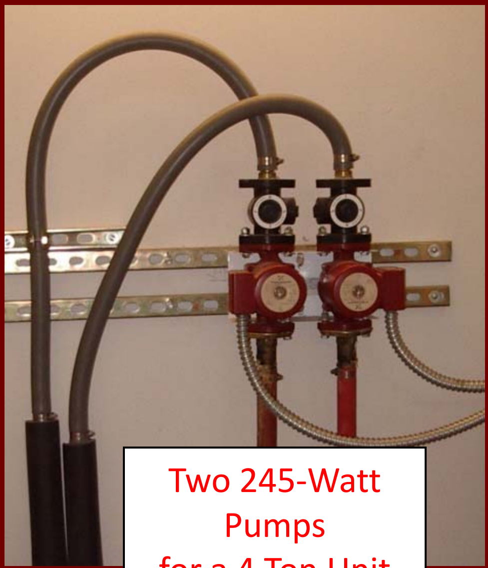
Questions?
Comments?
Discussion?

Session 4

PIPING AND PUMPS FOR CLOSED-LOOP GROUND-SOURCE HEAT PUMPS

Why Some GSHP Systems Use More Energy than Advertised

Two 385-Watt Pumps for a 5 Ton Unit



Two 245-Watt Pumps for a 4 Ton Unit

75 hp Pump for 500 Ton System

Expanded Table for Pump Power Grade

Installed Pump Power	Power into Pump Motor	GRADE	Available Head w/70% Eff. Pump at 3 gpm/ton
< 5 hp/100 tons	< 45 W/ton	A	< 46 ft. of water
5 < hp/100 tons ≤ 7.5	45 < W/ton ≤ 65	B	46 to 69 ft. of water
7.5 < hp/100 tons ≤ 10	65 < W/ton ≤ 85	C	69 to 92 ft. of water
10 < hp/100 tons ≤ 15	85 < W/ton ≤ 125	D	92 to 138 ft. of water
> 15 hp/100 tons	> 125 W/ton	F	> 138 ft. of water
Installed Pump Power	**Power into Pump Motor**	**GRADE**	**Available Pressure w/70% Eff. Pump at 3 Lpm/kW**
$< 10.5\ W_m/kW_t$	$< 13\ W_e/kW_t$	A	< 140 kPa
$10.5 < W_m/kW_t \leq 16$	$13 < W_e/kW_t \leq 19$	B	140 to 210 kPa
$16 < W_m/kW_t \leq 21$	$19 < W_e/kW_t \leq 25$	C	210 to 280 kPa
$21 < W_m/kW_t \leq 32$	$25 < W_e/kW_t \leq 36$	D	280 to 420 kPa
$> 32\ W_m/kW_t$	$> 36\ W_e/kW_t$	F	> 420 kPa

$W_m \equiv$ Watts Mechanical, $W_e \equiv$ Watts Electrical, $kW_t \equiv$ Kilowatts Thermal

Ensuring High GSHP Efficiency with Minimal Head Loss and Smaller Pumps

How's it done? For unitary and residential systems: Use 1 in. (32 mm) U-tubes ***and*** 1.5 in. (40 mm) or 2 in. (50 mm) headers

Standard Unitary Practice
Two 385 W pumps on 5 ton unit
EER = 61,600 Btu/h ÷ (4020 + 2 × 385 W)
EER = 12.9 Btu/W·h (COP = 3.8)

Smarter Unitary Practice
One 385 W pump on 5 ton Unit
EER = 61,600 Btu/h ÷ (4020 + 385 W)
EER = 14.0 Btu/W·h (COP = 4.1)

Even Smarter Unitary Practice
One 245 W pump on 5 ton unit
EER = 61,400 Btu/h ÷ (4020 + 245 W)
EER = 14.3 Btu/W·h (COP = 4.2)

Head Loss with ¾ in. (25 mm) U-Tubes and 1¼ in. (40 mm) Headers

								Rated	Rated Δh	Inlet	Inlet		Rated					
Liquid	20% Prop Glycol	➔	Percent by Volume			**Coils**	Flow	Flow	@ 60°F	Size	Vel	Re(in)	Vel		Re(rated)			Δh
Temp	40	°F					gpm	gpm	ft. water	inches	fps		fps					Ft. Liquid
Den	64.0	lbm/ft3				Heat Pump	15	15	11.5	1	6.1	14130	6.1		41123			12.6
Vis	2.31E-03	lbm/ft-s	3.44	cps							0.0	0	0.0		0			0.0
							0	0	0	0	0.0	0	0.0		0			0.0
	HDPE Piping														**Coil sub-total**			**12.6**
Flow	Nom. Dia.	DR	I.D.		Vel	Re	Δh(ft)	Length	Fittings	Leqv	Qty.	Fittings	Leqv	Qty.	Fittings	Leqv	Qty.	Δh
gpm	Inches	OD ÷ t	in.		fps		100 ft.	ft.		ft			ft			ft		Ft. Liquid
15	1.25	11	1.36		3.3	10404	4.65	150	Butt90	10	4	ButtRed	5	2	5-LoopHdrLas	30	2	12.1
3	0.75	11	0.86		1.7	3290	2.57	500	UniCoil	8	1	Butt90	5	2	ButtRed	4	2	13.5
	3	11	2.86		0.0	0	0.00	0	Butt90	26	2	ButtRed	10	2	Butt90	26	2	0.0
	2	11	1.94		0.0	0	0.00	0	Butt90	17	2	ButtRed	7	2	ButtRed	7	2	0.0
	2	11	1.94		0.0	0	0.00	0	Butt90	17	2	ButtRed	7	2	ButtRed	7	2	0.0
	1.25	11	1.36		0.0	0	0.00	0	Butt90	10	2	ButtRed	5	2	ButtRed	5	2	0.0
															HDPE sub-total			**25.6**
						Other		Cv		Inlet	Inlet		Rated					
						Fittings	Flow	@ 60°F	Quanity	Size	Vel	Re(in)	Vel		Re(rated)			Δh
						& Valves	gpm	gpm		inches	fps		fps					Ft. Liquid
						ball valve	15	35	4	1	6.1	14130	14.3		95954			1.9
						1"x 3' host ki	15	16.4	2	1	6.1	14130	6.7		44961			4.3
						Y-strainer	15	28	1	1	6.1	14130	11.4		76763			0.7
															Fitting sub-total			**6.9**
												Open Sys Only		►►	**Elevation**	Feet		**0**
															Total Loss	Ft. Liquid		**45.2**

Reduce Head Loss with 1 in. (32 mm) U-Tubes, 1½ in. (50 mm) Headers, and 1¼-in. Hose Kits and Valves

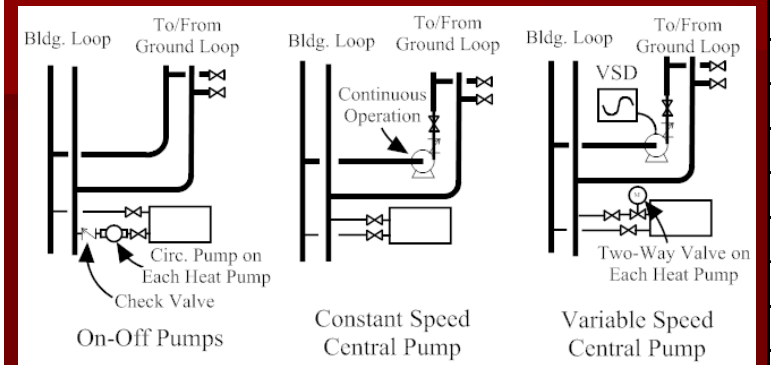
								Rated	Rated Δh	Inlet	Inlet		Rated					
Liquid	20% Prop Glycol	➔	Percent by Volume			**Coils**	Flow	Flow	@ 60ºF	Size	Vel	Re(in)	Vel		Re(rated)			Δh
Temp	40	ºF					gpm	gpm	ft. water	inches	fps		fps					Ft. Liquid
Den	64.0	lbm/ft3				Heat Pump	15	15	11.5	1	6.1	14130	6.1		41123			12.6
Vis	2.31E-03	lbm/ft-s	3.44	cps							0.0	0	0.0		0			0.0
							0	0	0	0	0.0	0	0.0		0			0.0
	HDPE Piping														**Coil sub-total**			**12.6**
Flow	Nom. Dia.	DR	I.D.		Vel	Re	Δh(ft)	Length	Fittings	Leqv	Qty.	Fittings	Leqv	Qty.	Fittings	Leqv	Qty.	Δh
gpm	Inches	OD ÷ t	in.		fps		100 ft.	ft.		ft			ft			ft		Ft. Liquid
15	1.5	11	1.55		2.5	9090	2.46	150	Butt90	12	4	ButtRed	6	2	5-LoopHdrLas	30	2	6.7
3	1	11	1.08		1.1	2627	0.74	500	UniCoil	10	1	Butt90	8	2	ButtRed	4	2	4.0
	3	11	2.86		0.0	0	0.00	0	Butt90	26	2	ButtRed	10	2	Butt90	26	2	0.0
	2	11	1.94		0.0	0	0.00	0	Butt90	17	2	ButtRed	7	2	ButtRed	7	2	0.0
	2	11	1.94		0.0	0	0.00	0	Butt90	17	2	ButtRed	7	2	ButtRed	7	2	0.0
	1.25	11	1.36		0.0	0	0.00	0	Butt90	10	2	ButtRed	5	2	ButtRed	5	2	0.0
															HDPE sub-total			**10.6**
						Other		Cv		Inlet	Inlet		Rated					
						Fittings	Flow	@ 60ºF	Quanity	Size	Vel	Re(in)	Vel		Re(rated)			Δh
						& Valves	gpm	gpm		inches	fps		fps					Ft. Liquid
						ball valve	15	47	4	1.25	3.9	11304	12.3		103082			1.1
						3' host kit	15	34.1	2	1.25	3.9	11304	8.9		74789			1.1
						Y-strainer	15	43	1	1.25	3.9	11304	11.2		94309			0.3
															Fitting sub-total			**2.5**
												Open Sys Only		►►	**Elevation**	Feet		**0**
															Total Loss	Ft. Liquid		**25.8**

Notes on U-Tube Size to Limit Head Loss

- For HPDE with water
  1. Limit ¾ in. DR 11 to 250 ft bores (500 ft of pipe)
  2. Limit 1 in. DR 11 to 350 ft bores (700 ft of pipe)
  3. Limit 1¼ in. DR 11 (or DR 9) to 500 ft bores (1000 ft of pipe)*
- For HPDE in heating-dominant buildings with water/antifreeze mixtures
  1. Limit ¾ in. DR 11 to 200 ft bores (500 ft of pipe)
  2. Limit 1 in. DR 11 to 300 ft bores (600 ft of pipe)
  3. Limit 1¼ in. DR 11 (or DR 9) to 450 ft bores (900 ft of pipe)*
- For cross-linked polyethylene (PEX)
  1. Caution advised because PEX inside diameters are based on copper tube size (CTS) and DR 9. Actual diameters are much smaller for the same nominal diameter for HDPE tubes which are based on larger iron pipe size (IPS) diameters.
  2. Below-grade mechanical joints are to be avoided at all cost.

* Consider DR 9 for bores greater than 400 ft

Pump Energy and Operating Cost Comparison



	On-Off Pump KWh		Const. Pump KWh		Var .Spd. Pump KWh	
%Full Load	Cooling	Heating	Cooling	Heating	Cooling	Heating
0%	0	0	1773	1773	299	299
10%	141	125	997	887	168	149
20%	209	181	742	643	125	108
30%	220	188	521	443	88	75
40%	200	175	355	310	85	74
50%	180	148	255	211	82	68
60%	141	122	166	144	70	61
70%	98	88	100	89	54	48
80%	88	75	78	66	52	45
90%	70	56	55	44	47	37
100%	47	31	33	22	34	23
	1394	1189	5075	4632	1104	987
Totals	2583	$310	9707	$1,165	2090	$251

Not Oversized

	On-Off Pump KWh		Const. Pump KWh		Var .Spd. Pump KWh	
%Full Load	Cooling	Heating	Cooling	Heating	Cooling	Heating
0%	0	0	2660	2660	742	742
10%	211	188	1496	1330	417	371
20%	314	272	1114	964	311	269
30%	331	281	781	665	218	185
40%	300	263	532	465	148	130
50%	270	223	382	316	123	102
60%	211	183	249	216	105	91
70%	148	131	150	133	80	71
80%	131	113	116	100	79	67
90%	105	84	83	66	70	56
100%	70	47	50	33	51	34
	2091	1784	7613	6948	2344	2119
Totals	3875	$465	14561	$1,747	4463	$536

50% Oversized

(VS drives operate at minimum speed for many more hours)

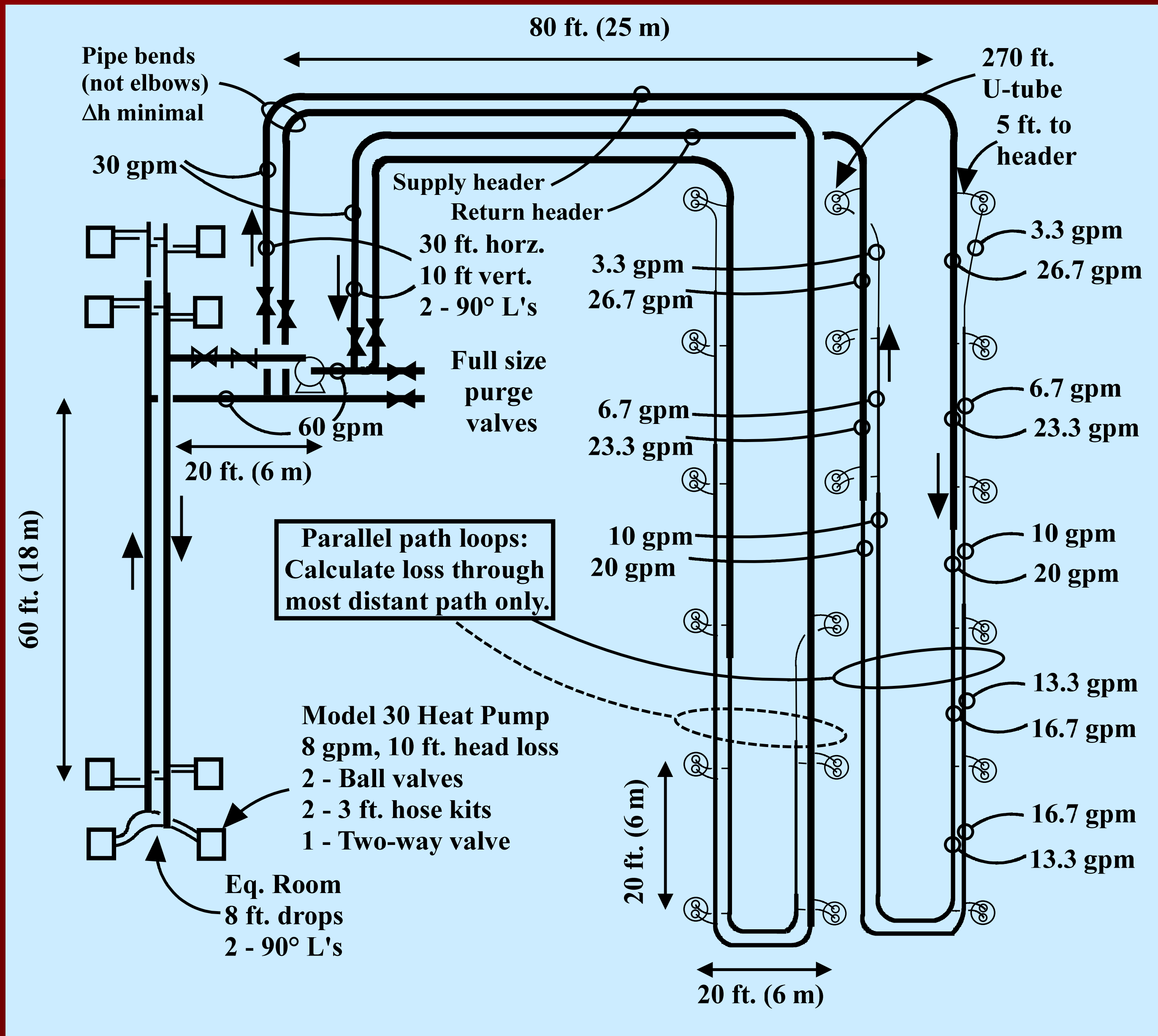
Exterior Pipe: HDPE with Dimension Ratio (DR = OD/t)
IP: OD = Schedule Pipe OD, ID = OD(1-2/DR)
SI: OD (mm) = 25, 32, 40, 50, 63…, ID = OD(1-2/DR)

Interior Pipe: Steel, HDPE, and New Fiber-Core Polypropylene

Closed-Loop GSHP Water Loop Design

1. Layout piping network: lengths, fittings, and section flows
2. Size pipe for each section with acceptable head loss (<3 ft/100 ft)
3. Include full-size purge valves in convenient and safe locations
4. Find equivalent length of longest/critical path(s)
5. Find head loss through other components (most remote heat pump, hose kits, control valves, strainers, etc.)
6. Resize any pipe sections and components with high losses
7. Sum losses in critical flow path (do not include losses in parallel circuits)
8. Select pump and motor to operate within ±5% of pump best operating point (BEP)
9. Calculate required pump power (hp/100 ton) or demand (W/ton or W/kW); redesign system if grade of A or B is not achieved (See Pump Power Grade Table—third slide this session)

Example Head Loss: Steps 1, 2, and 3



Example Design: Spreadsheet Calculation

HDPE Ground Loop and Building Loop

Liquid	Water			
Temp	85	°F		
Den	62.14	lbm/ft3		
Vis	5.44E-04	lbm/ft-s	0.81	cps

Coils	Flow gpm	Rated Flow gpm	Rated Δh @ 60°F ft. water	Inlet Size inches	Inlet Vel fps	Re(in)	Rated Vel fps	Re(rated)	Δh Ft. Liquid
Heat Pump	8	8	10	1	3.3	31093	3.3	21932	9.7
					0.0	0	0.0	0	0.0
	0	0	0	0	0.0	0	0.0	0	0.0
								Coil sub-total	**9.7**

HDPE Piping - Ground Loop (9 U-tubes)

Flow gpm	Nom. Dia. Inches	DR OD ÷ t	I.D. in.	Roughness for HDPE in ft.	Vel fps	Re	Δh(ft) 100 ft.	Length ft.	Fitting Selector	Leqv ft	Qty.	Fitting Selector	Leqv ft	Qty.	Fitting Selector	Leqv ft	Qty.	Δh Ft. Liquid	
30.0	2	11	1.94	7.0E-05	3.2	60004	2.20	130	Butt90	17	2	ButtRed	7	0	5-LoopHdrLast	30	0	3.6	Supply Header
26.7	2	11	1.94	7.0E-05	2.9	53337	1.77	20	ButtTeeRun	4	1	ButtTeeRun	4	0	ButtRed	7	0	0.4	After 1st U-tube take off
23.3	2	11	1.94	7.0E-05	2.5	46670	1.39	20	ButtTeeRun	4	1	ButtRed	7	0	5-LoopHdrLast	30	0	0.3	After 2nd U-tube take off
20.0	2	11	1.94	7.0E-05	2.2	40003	1.05	20	ButtTeeRun	4	1	ButtRed	7	1	5-LoopHdrLast	30	0	0.3	After 3rd U-tube take off
16.7	1.5	11	1.55	7.0E-05	2.8	41669	2.24	20	ButtTeeRun	3	1	ButtRed	6	0	5-LoopHdrLast	30	0	0.5	After 4th U-tube take off
13.3	1.25	11	1.36	7.0E-05	3.0	38155	2.88	20	ButtTeeRun	3	1	ButtRed	5	1	5-LoopHdrLast	30	0	0.8	After 5th U-tube take off
10.0	1.25	11	1.36	7.0E-05	2.2	28616	1.71	80	ButtTeeRun	3	1	ButtRed	5	0	5-LoopHdrLast	30	0	1.4	After 6th U-tube take off
6.7	1	11	1.08	7.0E-05	2.4	24083	2.56	20	ButtTeeRun	3	1	ButtRed	4	0	5-LoopHdrLast	30	0	0.6	After 7th U-tube take off
3.3	1	11	1.08	7.0E-05	1.2	12041	0.74	565	UniCoil	10	1	ButtRed	4	0	5-LoopHdrLast	30	0	4.3	U-tube
30.0	2	11	1.94	7.0E-05	3.2	60004	2.20	110	Butt90	17	2	ButtRed	7	0	5-LoopHdrLast	30	0	3.2	Return Header
															Grn Loop sub-total			**15.5**	

U-tube Re

HDPE Piping - Building Loop

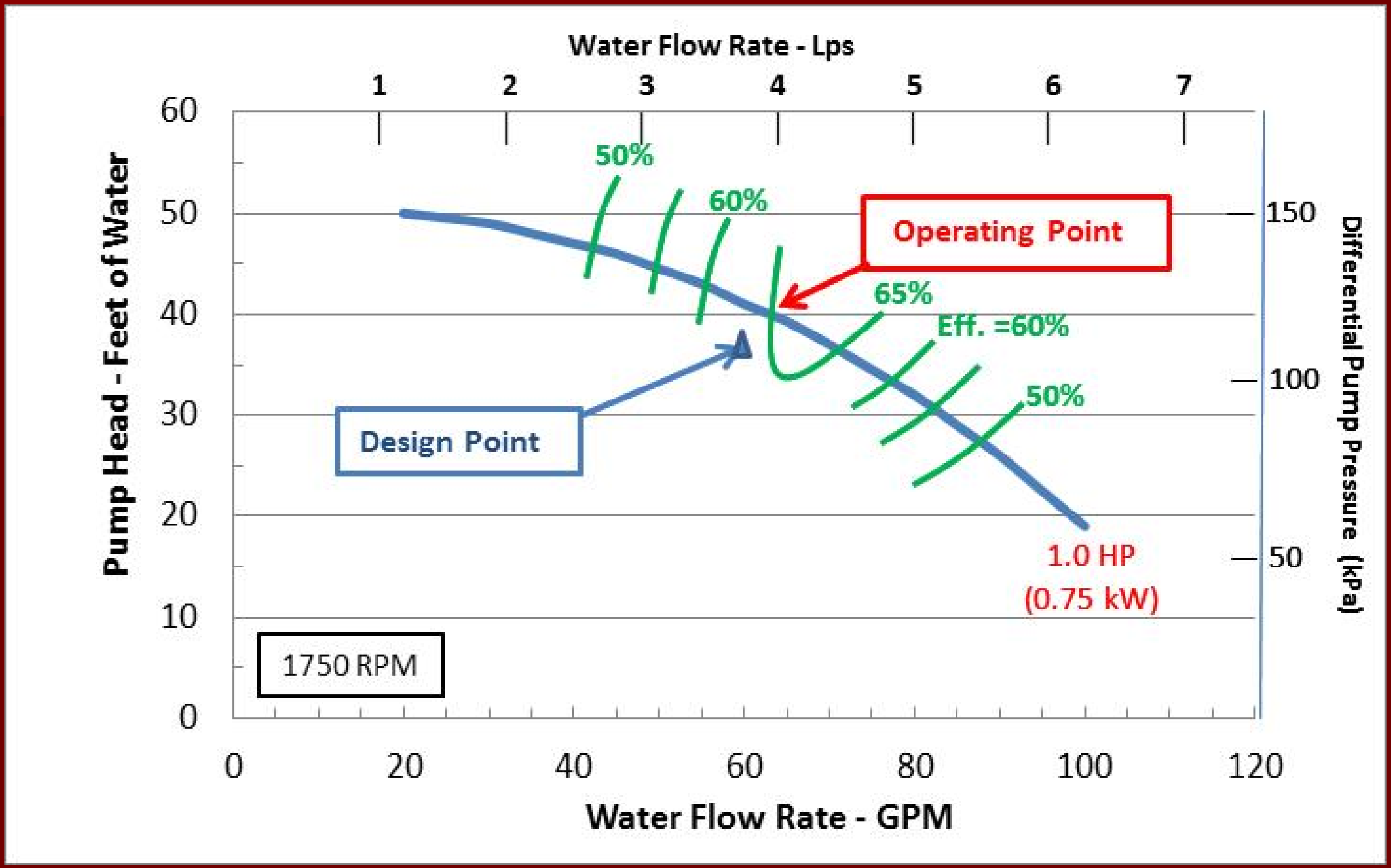
Flow gpm	Nom. Dia. Inches	DR OD ÷ t	I.D. in.	Roughness for HDPE in ft.	Vel fps	Re	Δh(ft) 100 ft.	Length ft.	Fitting Selector	Leqv ft	Qty.	Fitting Selector	Leqv ft	Qty.	Fitting Selector	Leqv ft	Qty.	Δh Ft. Liquid
30.0	2	11	1.94	0.00007	3.2	60004	2.20	5	ButtTeeBr	16	2	ButtRed	7	0	5-LoopHdrLast	30	0	0.8
60.0	3	11	2.86	0.00007	3.0	81434	1.17	25	ButtTeeBr	26	2	ButtRed	10	0	5-LoopHdrLast	30	0	0.9
30.0	2	11	1.94	0.00007	3.2	60004	2.20	136	ButtTeeBr	16	4	ButtRed	7	0	5-LoopHdrLast	30	0	4.4
	1.25	11	1.36	0.00007	0.0	0	0.00	0	Butt90	10	2	ButtRed	5	0	5-LoopHdrLast	30	0	0.0
	1.25	11	1.36	0.00007	0.0	0	0.00	0	Butt90	10	2	ButtRed	5	0	5-LoopHdrLast	30	2	0.0
	1.25	11	1.36	0.00007	0.0	0	0.00	0	Butt90	10	2	ButtRed	5	0	5-LoopHdrLast	30	0	0.0
															HDPE sub-total			**6.1**

Steel/Brass/PVC - Valves and Fittings

Flow gpm	Nom. Dia. Inches	Schedule 40 or 80	I.D. in.	Pipe Mat'l or Rghness in ft	Vel fps	Re	Δh(ft) 100 ft.	Length ft.	Fitting Selector	Leqv ft	Qty.	Fitting Selector	Leqv ft	Qty.	Fitting Selector	Leqv ft	Qty.	Δh Ft. Liquid
60.0	3	40	3.07	Steel-Old	2.6	76009	1.10	0	Gate Valve	8.3	2	Gate Valve	8.3	0	Gate Valve	8.3	0	0.2
	3	40	3.07	Steel-Old	0.0	0	0.00	0	Gate Valve	8.3	0	T-Straight	10.0	0	Gate Valve	8.3	0	0.0
	3	40	3.07	Steel-Old	0.0	0	0.00	0	Gate Valve	8.3	0	T-Straight	10.0	0	Gate Valve	8.3	0	0.0

Other Fittings & Valves	Flow gpm	Cv @ 60°F gpm	Quanity	Inlet Size inches	Inlet Vel fps	Re(in)	Rated Vel fps	Re(rated)	Δh Ft. Liquid	
hose kit	8	8.2	2	0.75	5.8	41457	6.0	29974	4.3	
ball valves	8	23.5	2	0.75	5.8	41457	17.1	85901	0.5	
zone valve	8	25	1	0.75	5.8	41457	18.2	91384	0.2	
Strainer	60	160	1	3	2.7	77732	7.3	146215	0.3	
Swing Ck	60	195	1	3	2.7	77732	8.9	178200	0.2	
								Fitting sub-total	**5.7**	
						Open Systems Only ►►		**Elevation**	0	Feet
								Total Loss	**37.0**	Ft. Liquid

Select Pump(s)



Calculate Pump Power and/or Demand Grade

$$\frac{W_{Pump}(hp)}{100\ tons} = \frac{1.0\ hp}{21\ tons/100} = 4.8\frac{hp}{100\ tons}\ (10.2\ W_m/kW_t) \equiv Grade\ A$$

Output	Full-Load Efficiency		Part-Load Multipliers ($\eta_{PL} = PLM \times \eta_{FL}$)			
Power	~1800 rpm	~3600 rpm	Percent of Full Load			
(hp)	(4-Pole)	(2-Pole)	20%	40%	60%	80%
1	82.5%	74.0%	0.59	0.82	0.90	0.96
1.5	84.0%	81.5%				
2	84.0%	82.5%	0.66	0.93	1.00	1.00
3	87.5%	84.0%				
5	87.5%	86.5%				
7.5	90.2%	87.5%	0.80	0.96	1.00	1.00
10	90.2%	88.5%				
15	91.0%	89.5%				
20	91.7%	89.5%	0.87	0.98	1.00	1.00
25	92.4%	90.2%				
30	92.4%	90.2%				
40	93.0%	91.0%	0.92	0.99	1.00	1.00
50	93.6%	91.7%				

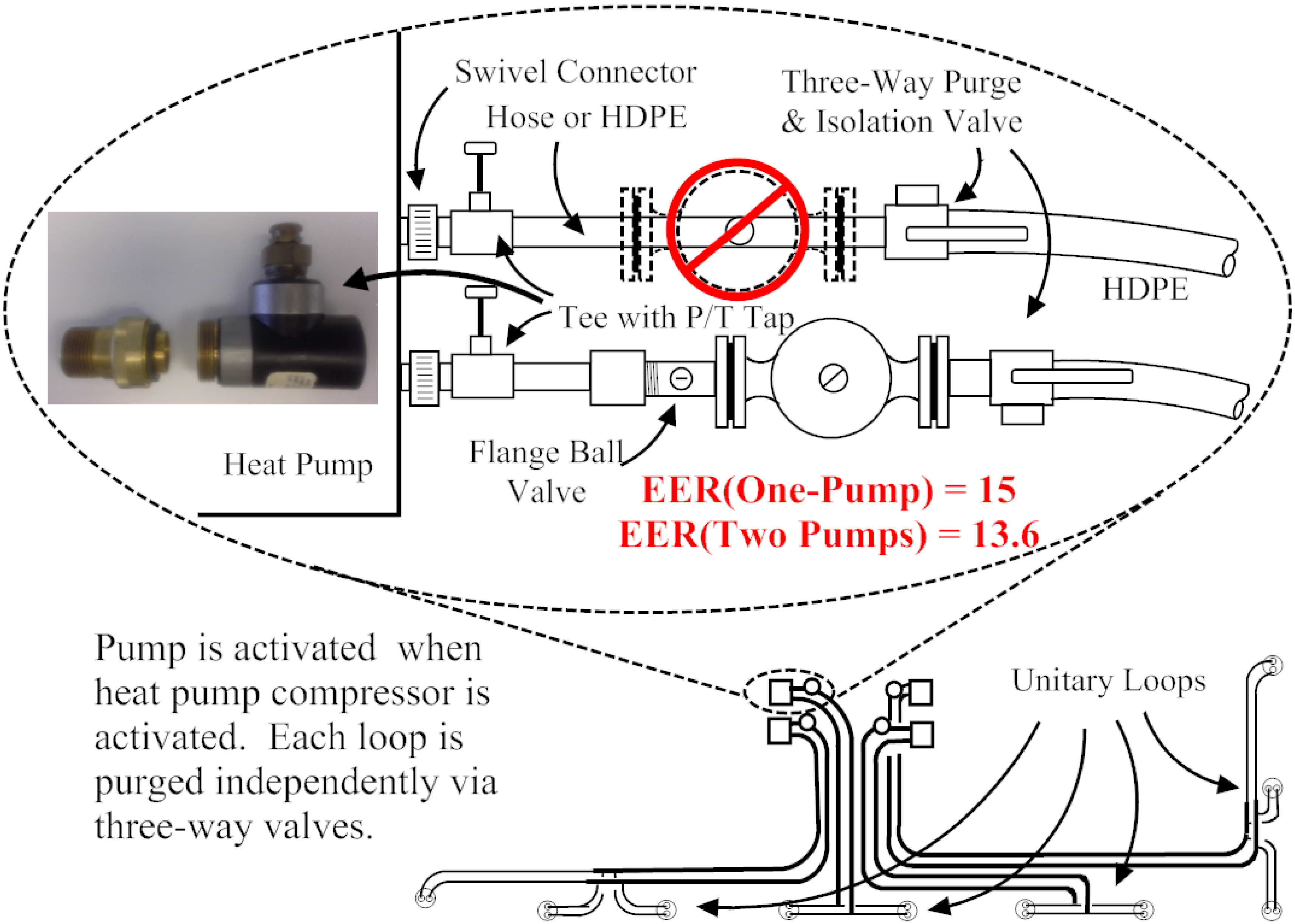
$$W_{Motor}(kW_e) = \frac{0.746\frac{kW}{hp} \times W_{Pump}(hp)}{\eta_{Motor} \times \eta_{VSD}}$$

$$= \frac{0.746\frac{kW}{hp} \times 1.0hp}{82.5\% \times 97\%} = 0.93\ kW$$

$$\frac{W_{motor}(W)}{ton} = \frac{0.93kW \times 1000W/kW}{21\ tons}$$

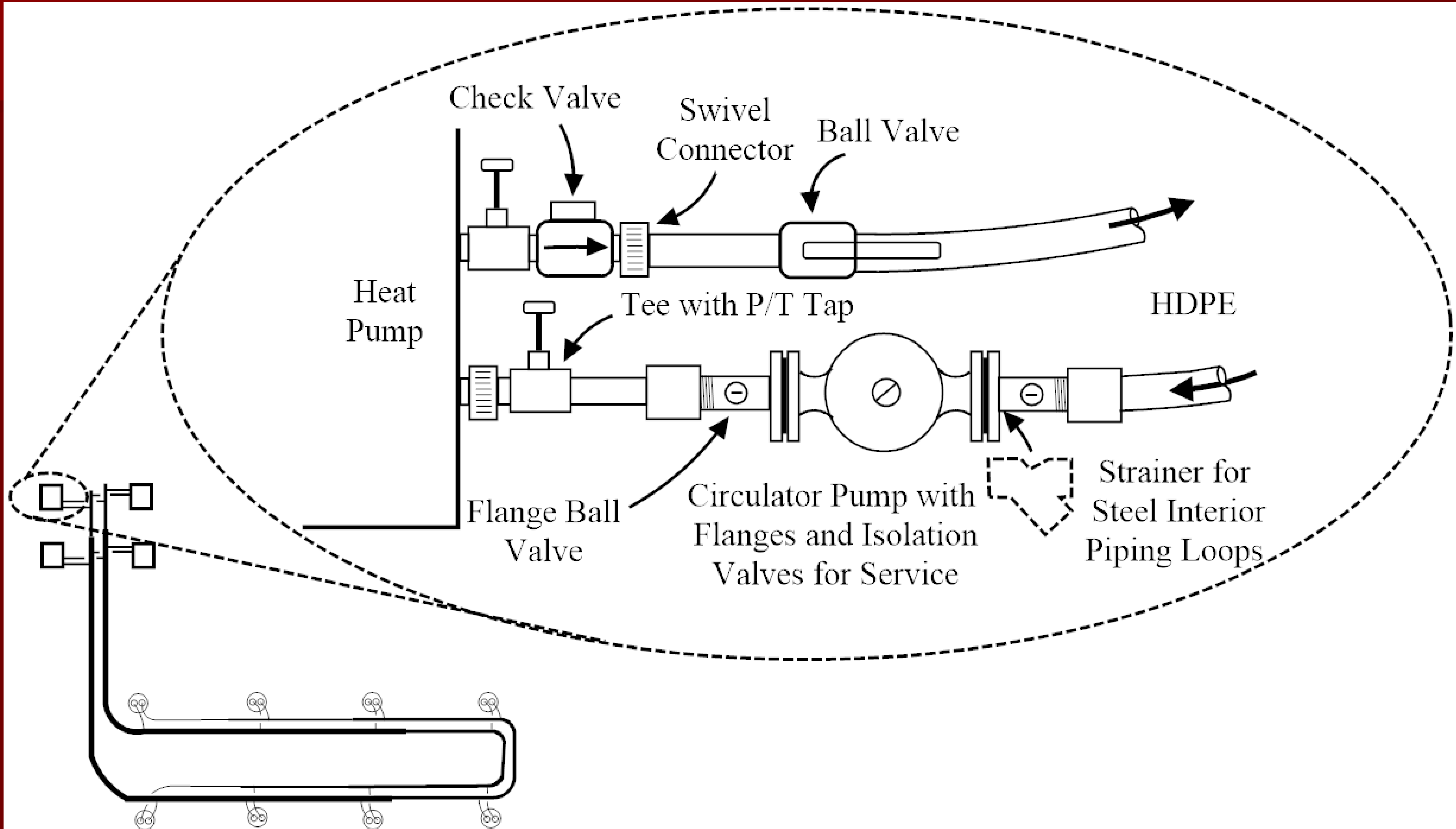
$$= 44\frac{W}{ton}(12.6\ W_e/kW_t)\ \equiv Grade\ A$$

Unitary Loop Pump Control and Connections

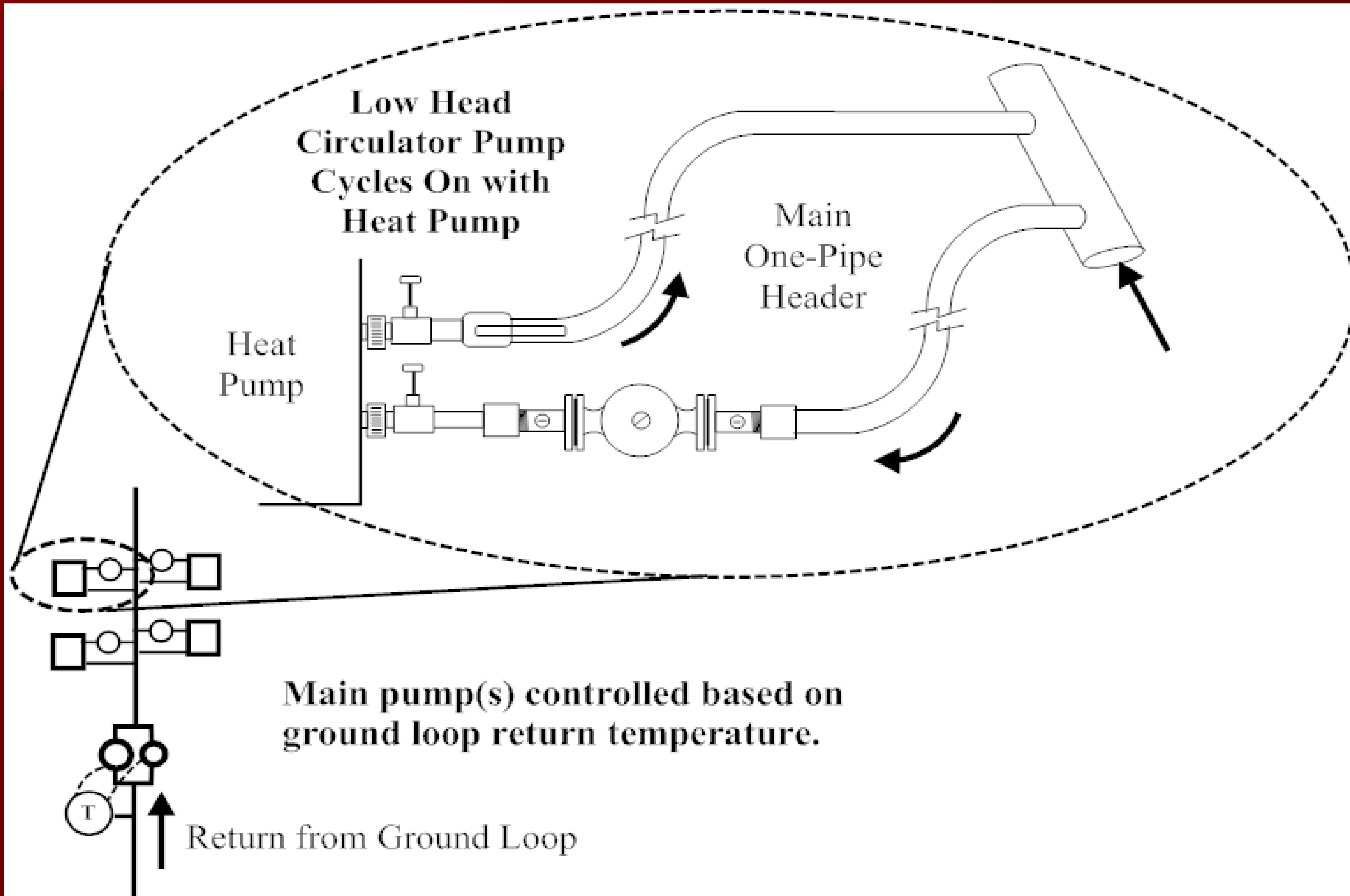


Pump is activated when heat pump compressor is activated. Each loop is purged independently via three-way valves.

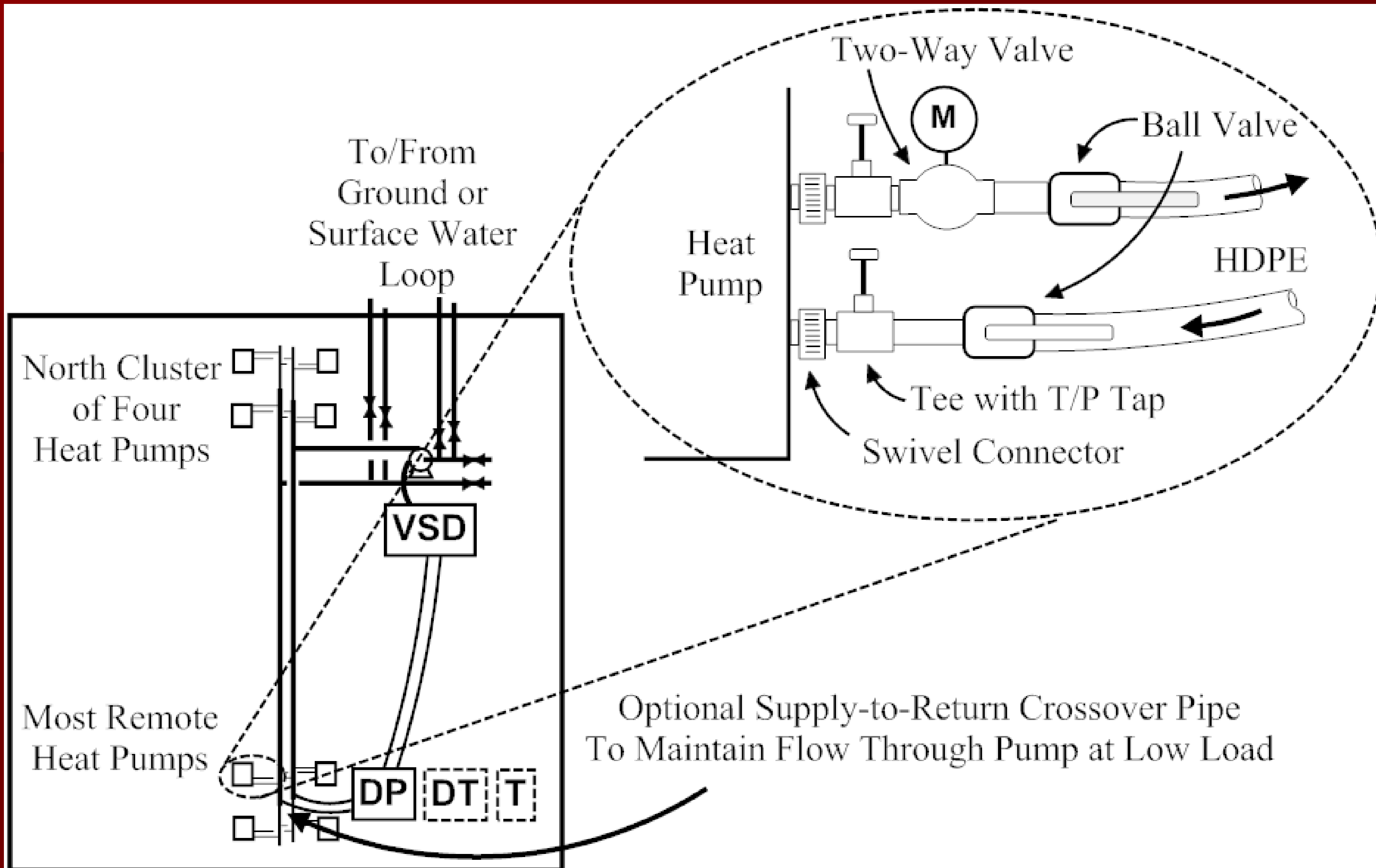
Common Loop Pump Control and Connections



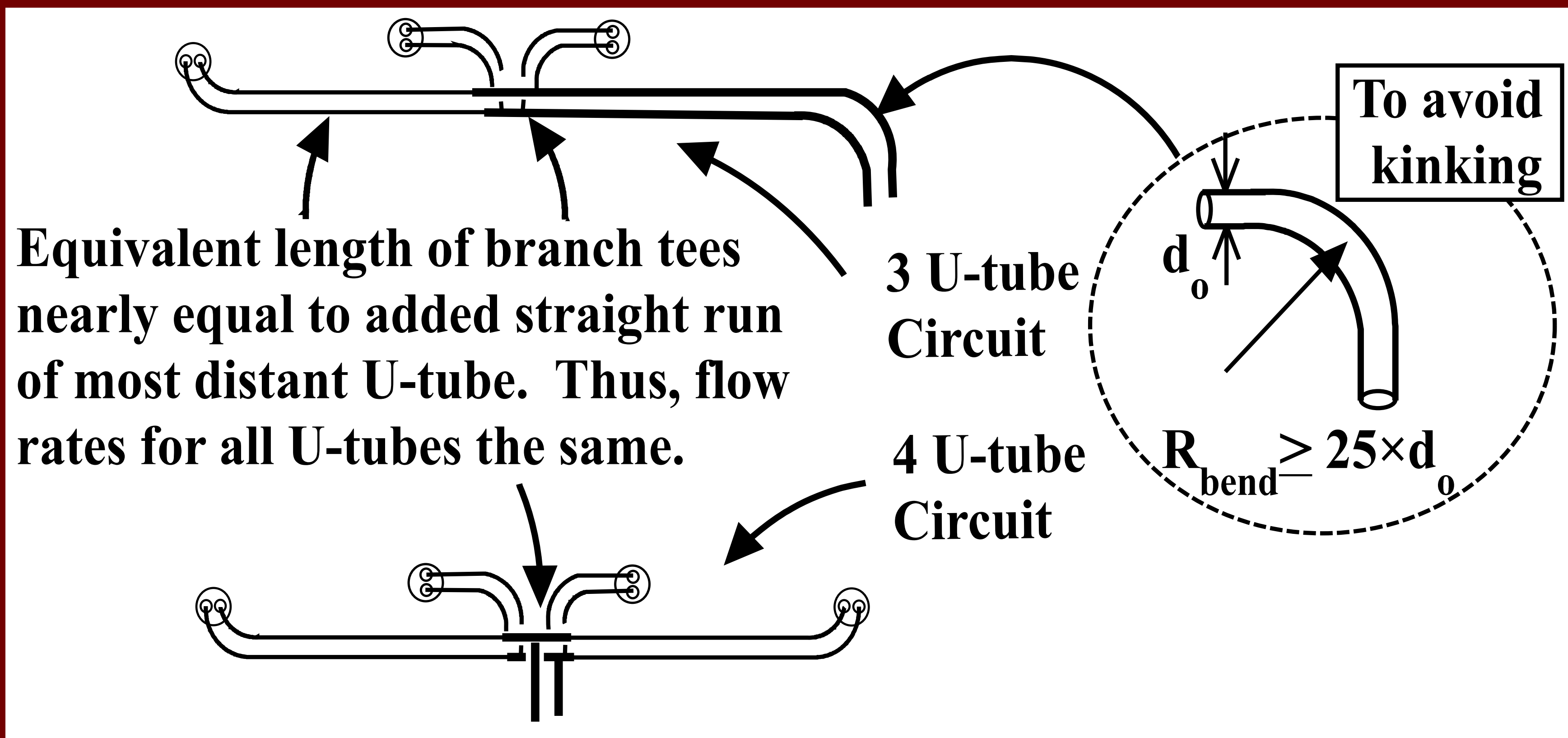
One-Pipe Loop Pump Control and Connections



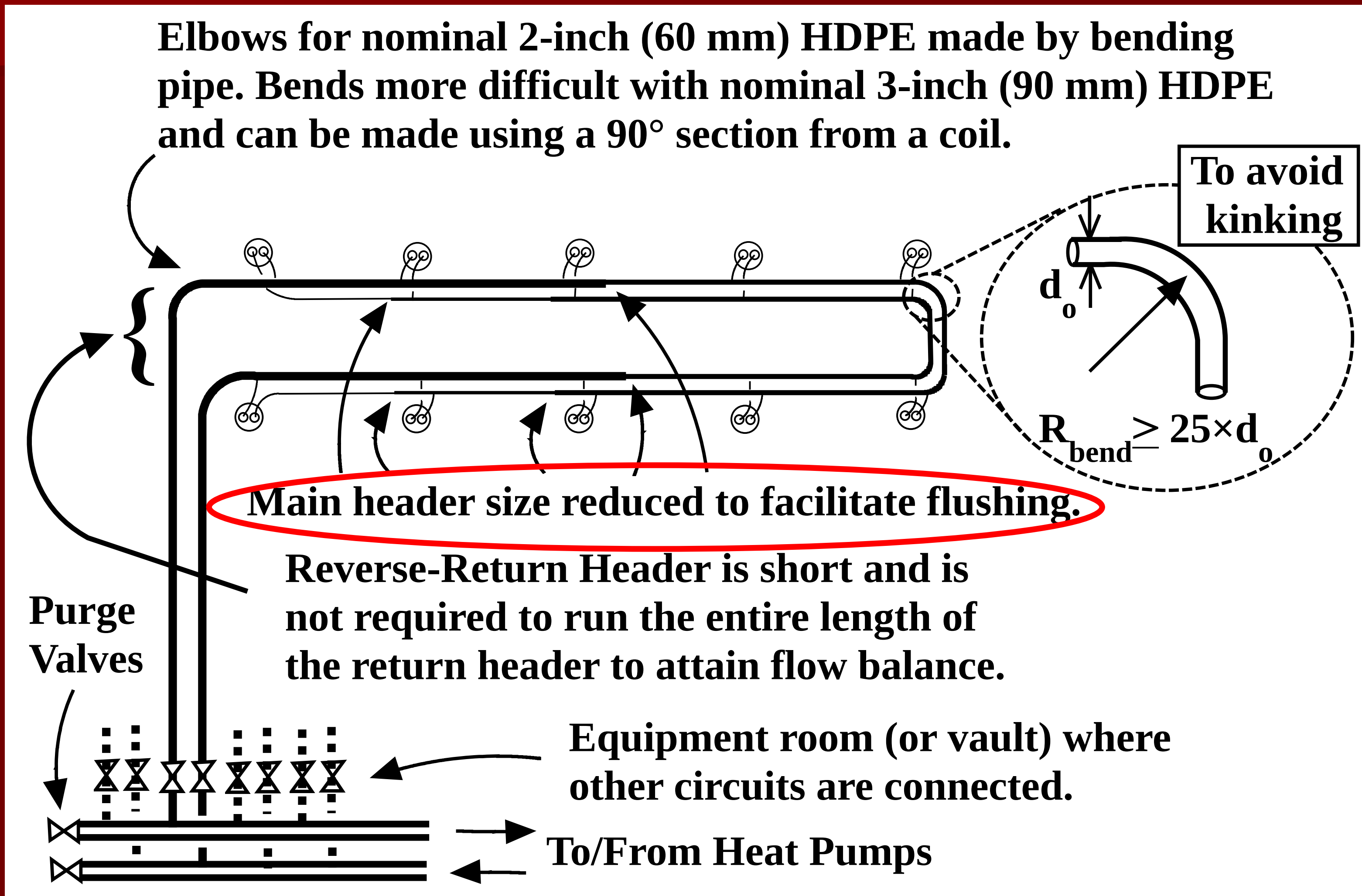
Central Loop Pump Control and Connections



Naturally Balanced, Small Parallel U-Tube Circuits

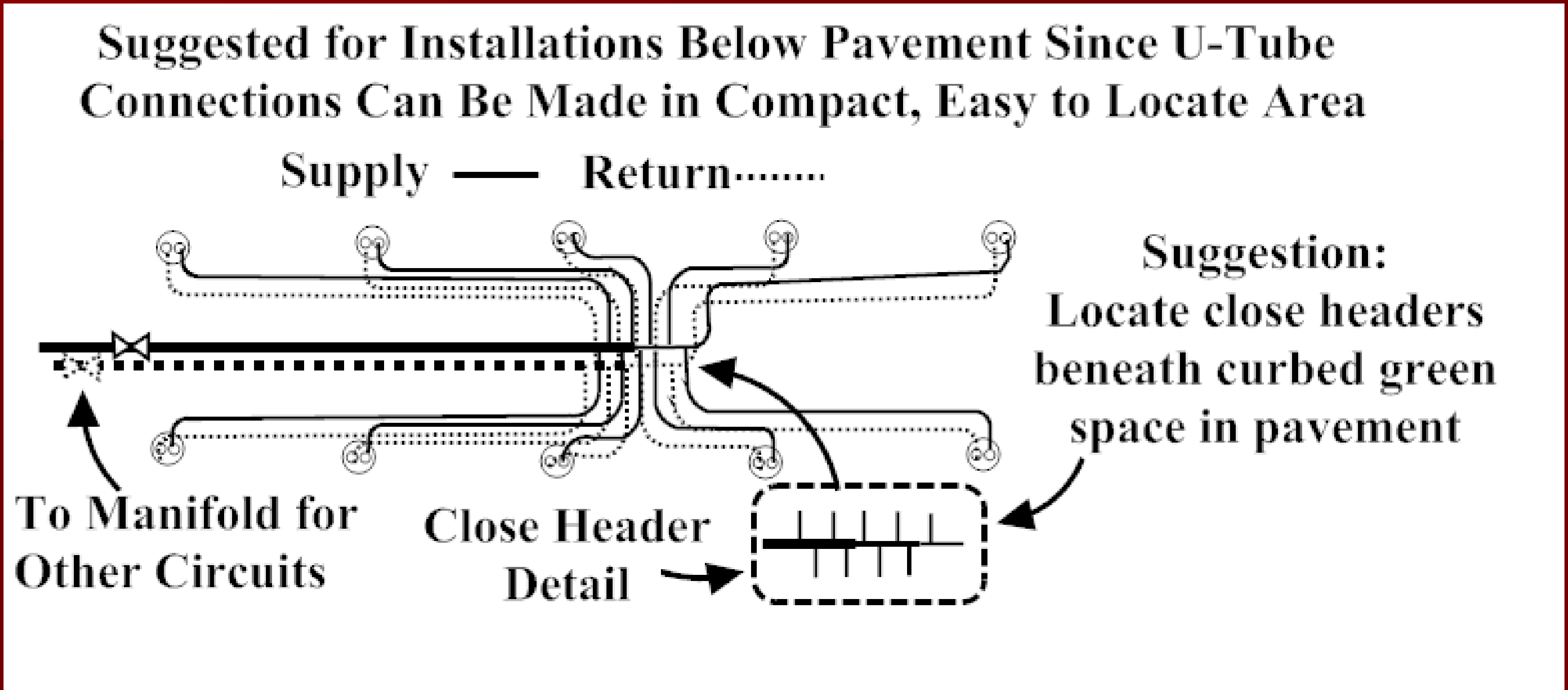


Naturally Balanced, Modified Reverse-Return U-Tube Circuits



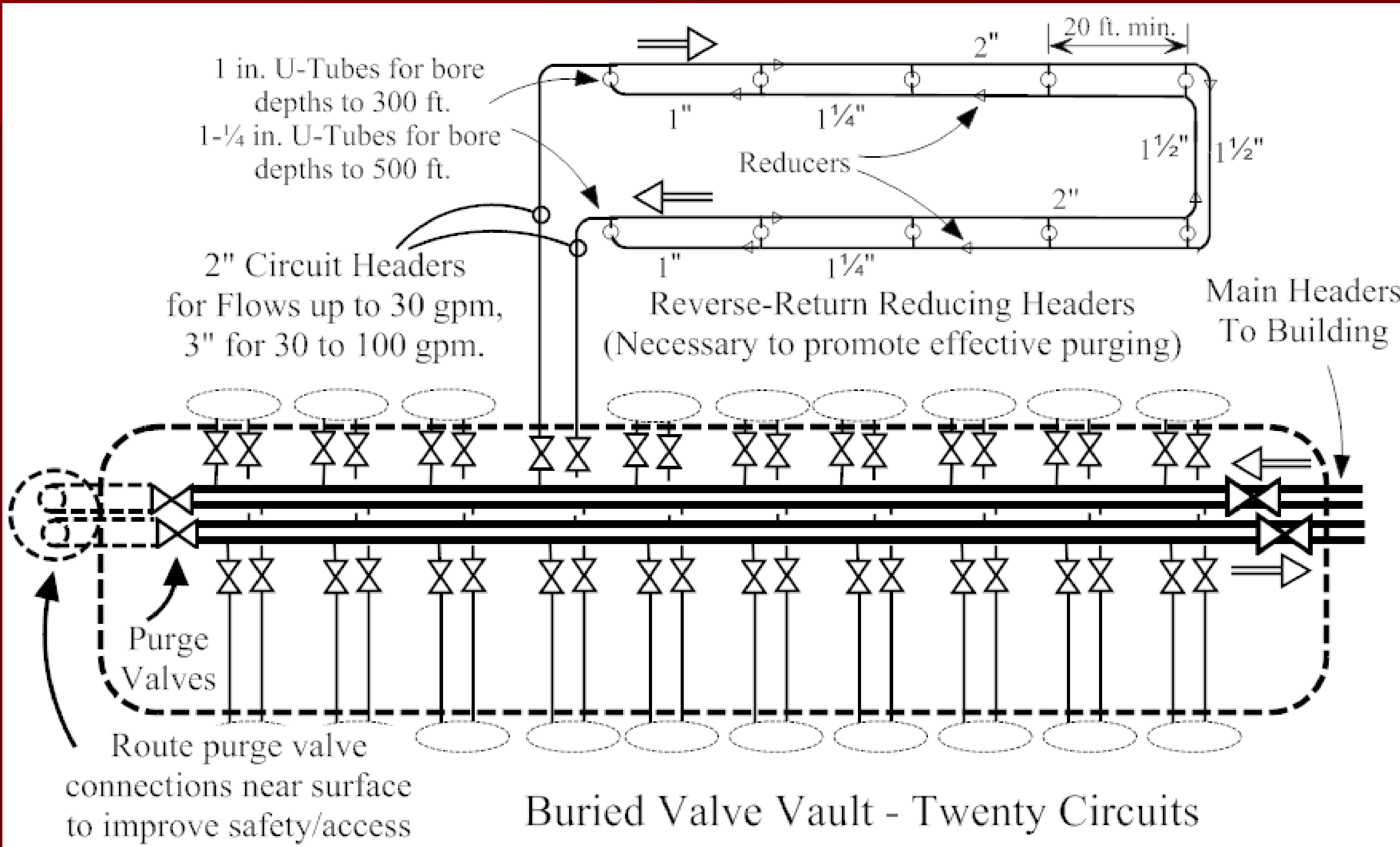
Vault or Equipment Room Manifold

Close Header U-Tube Circuits



Out of balance? Not much if U-tube bores are deep. Care required in labeling each U-tube to ensure supply and return header connections are correct.

Buried Valve Vault—Twenty Circuits



Purge Pumps for 10 to 25 Ton (35 to 90 kW) Ground Loop Circuits

Purge requirement being debated:
Original specification: 2 fps but poorly designed circuits may need up to 6 fps

Monster Purge Pump Used for Ground Loop Circuits without Isolation Valves

Debris Removed by Monster Purge Pump after Initial Purging Attempt of 300 Ton (1050 kW) Ground Loop with an Insufficient Number of Isolation Valves

Recommendations for Ground Loop Circuit Options

- Consult with reputable ground loop contractors to ascertain level of difficulty for options
- Request bids for alternate ground loop circuit options
- Avoid input from supply vendors unless they are willing to provide written prices for component options
- Verify local safety precautions required for burial depths greater than 4 ft (1.2 m) below grade
- For vaults, verify with local authorities for classification of and requirements for confined spaces

Questions?

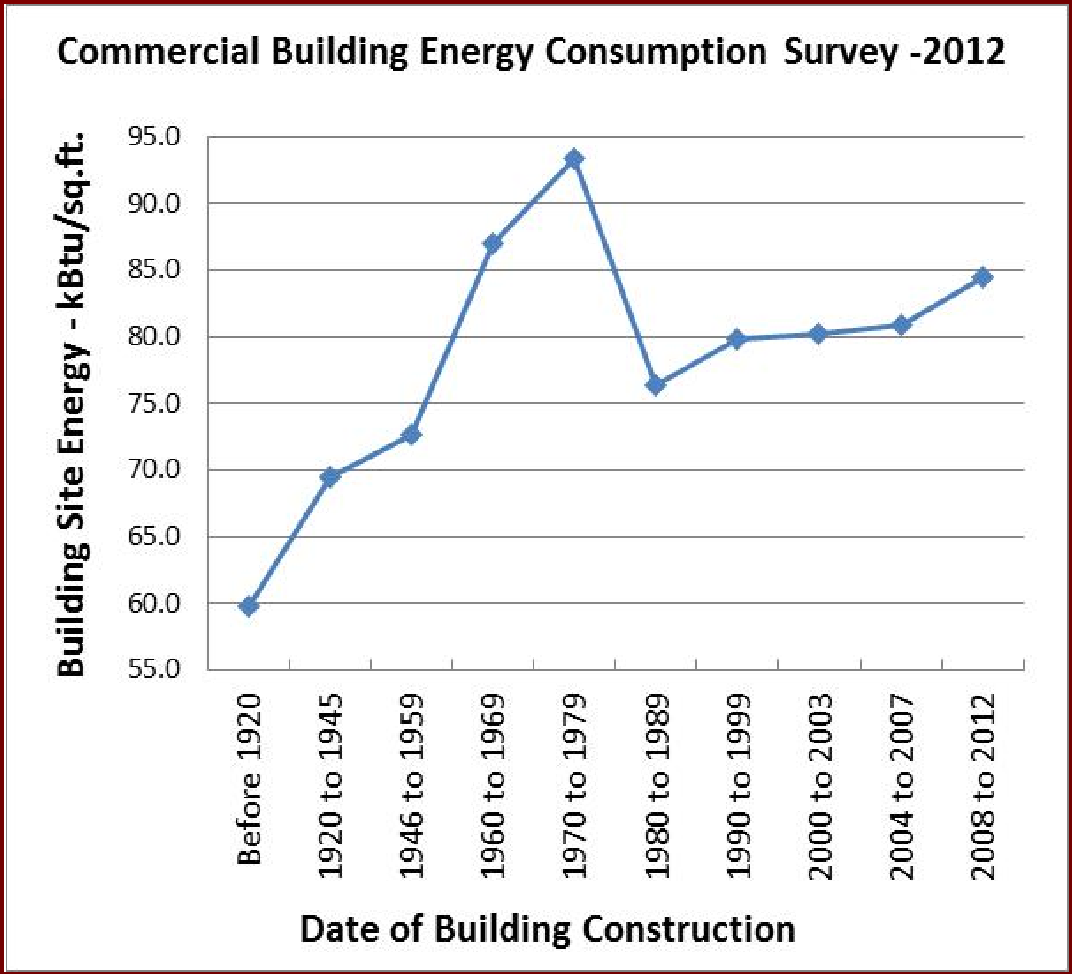
Comments?

Session 5

GSHP PERFORMANCE AND INSTALLATION COST

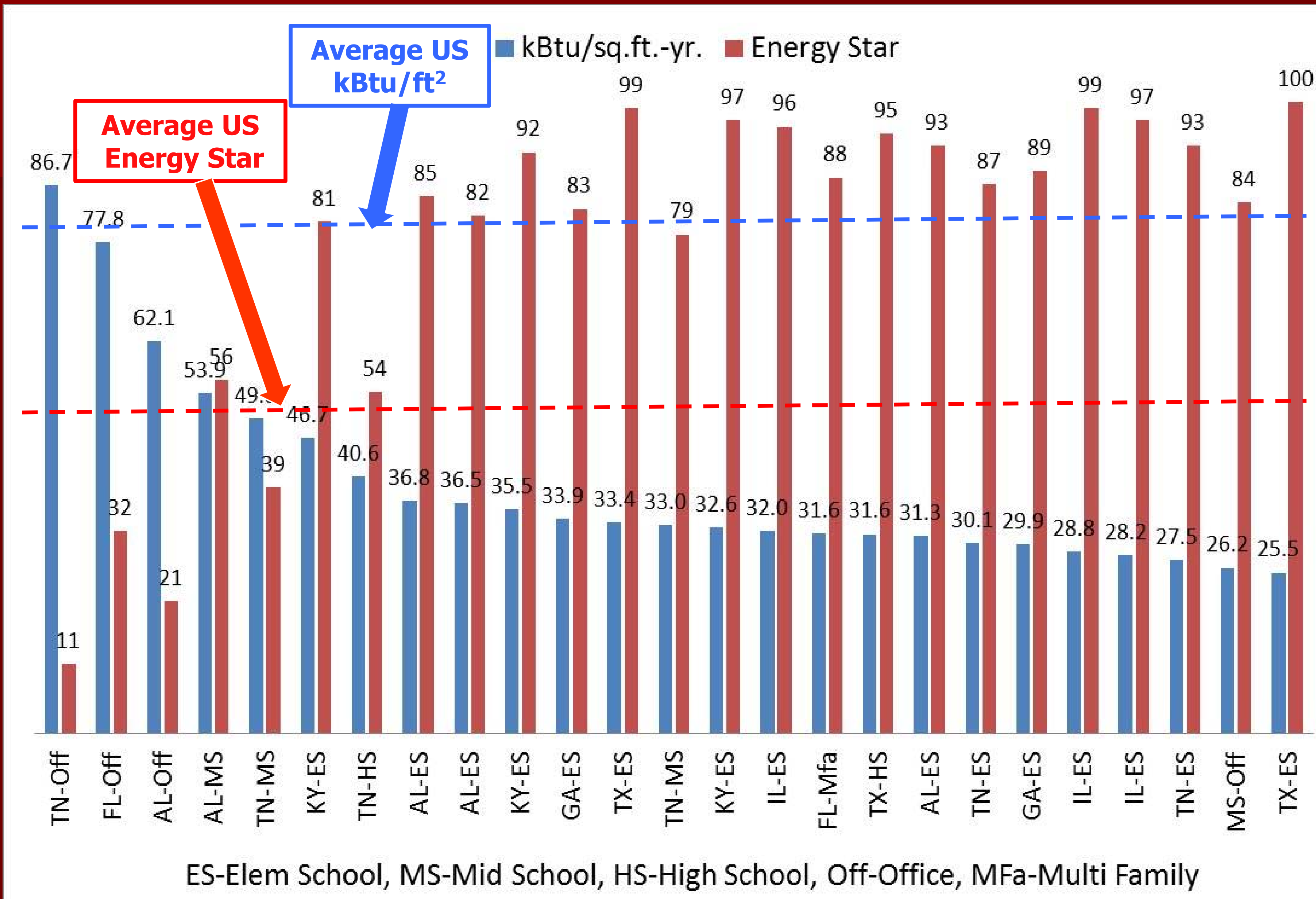
CBECS 2012 Compared to 2003

- Overall building energy intensity decreased from 89.8 to 80 kBtu/ft^2
- Total lighting energy (kBtu) down 46% and Heating down 20%
- Total ventilation energy and cooling energy increased substantially
- 2008–12 buildings used more energy than those built in 1980-2007

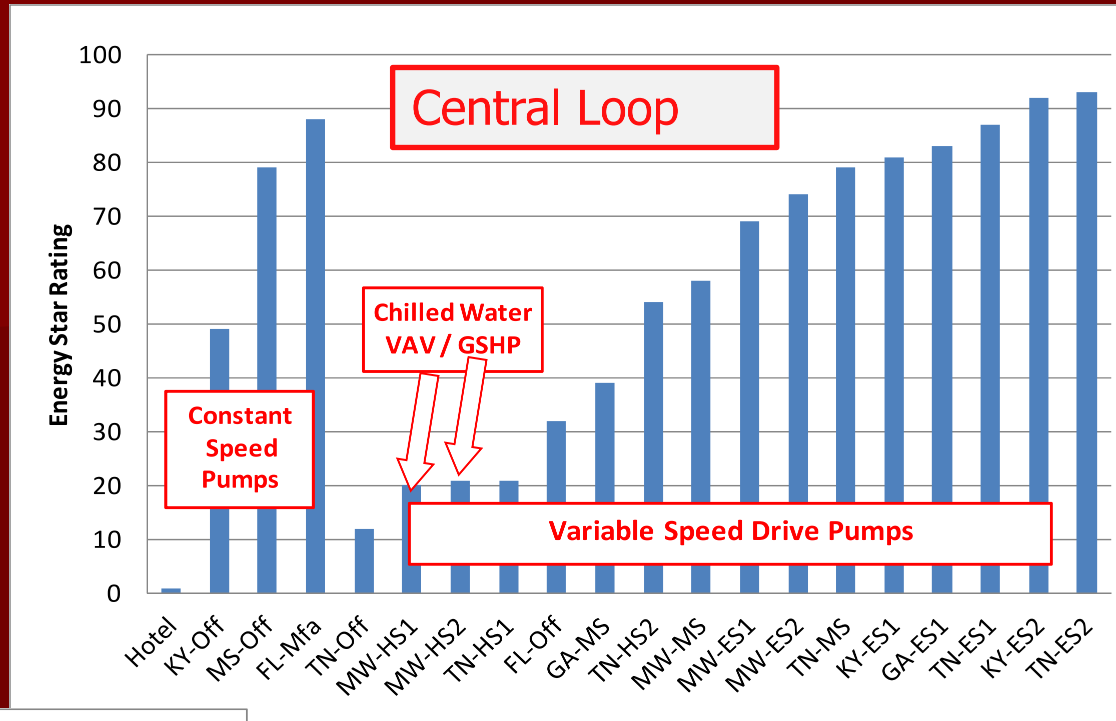


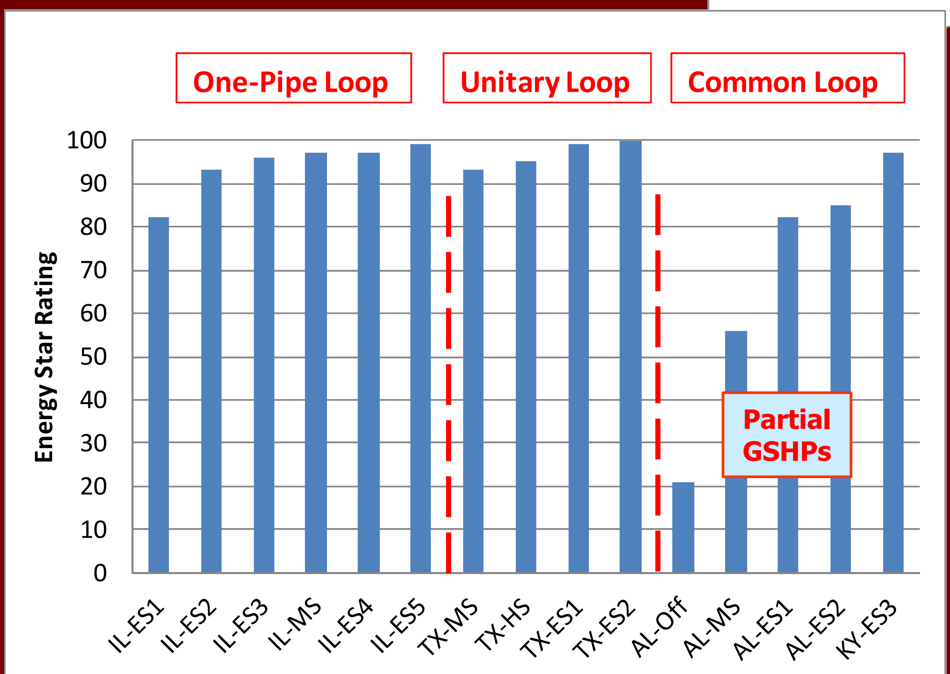
http://www.eia.gov/consumption/commercial/reports/2012/energyusage/index.cfm.

GSHP System Energy Consumption and ENERGY STAR Rating

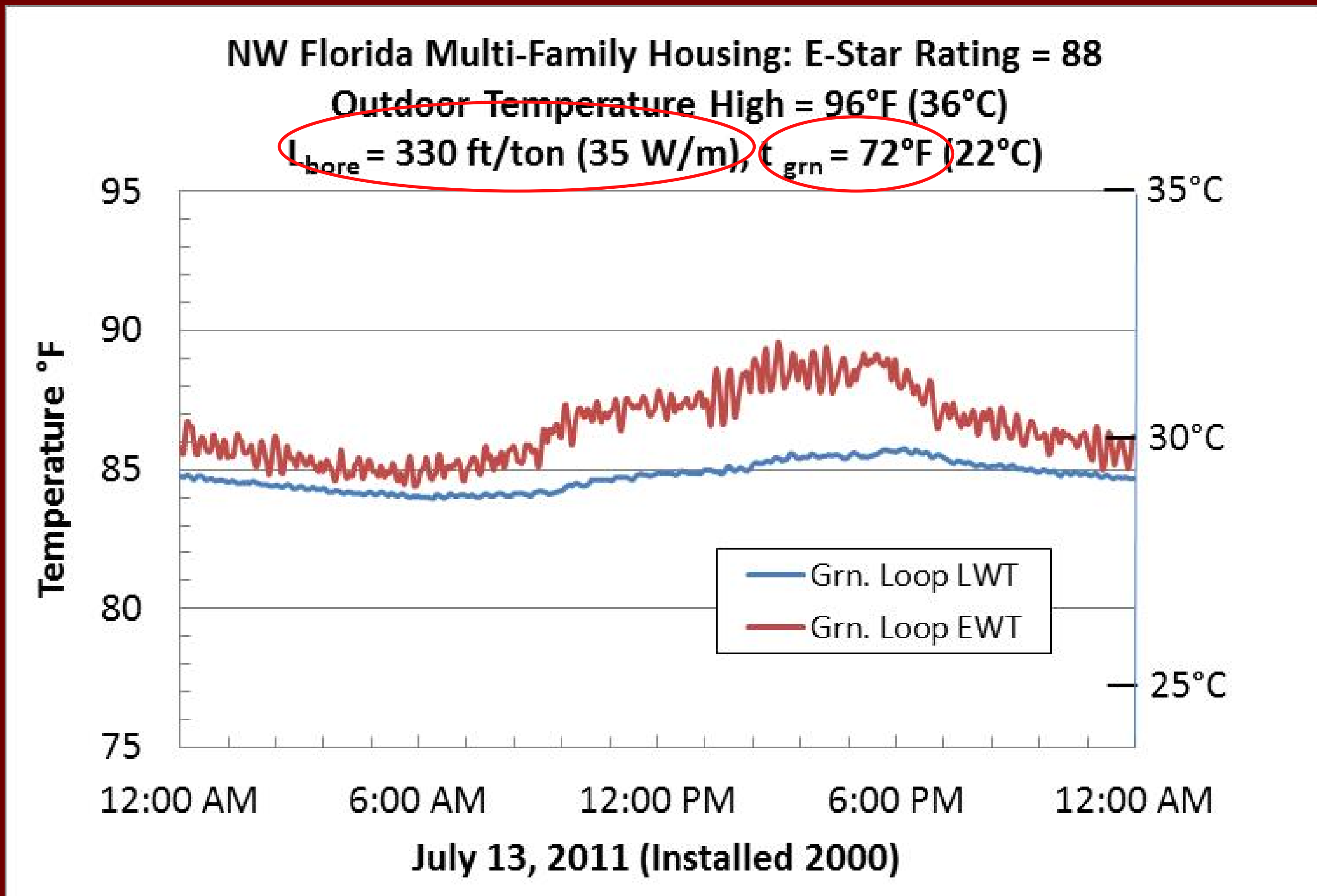


ENERGY STAR Rating and GCHP Loop Type

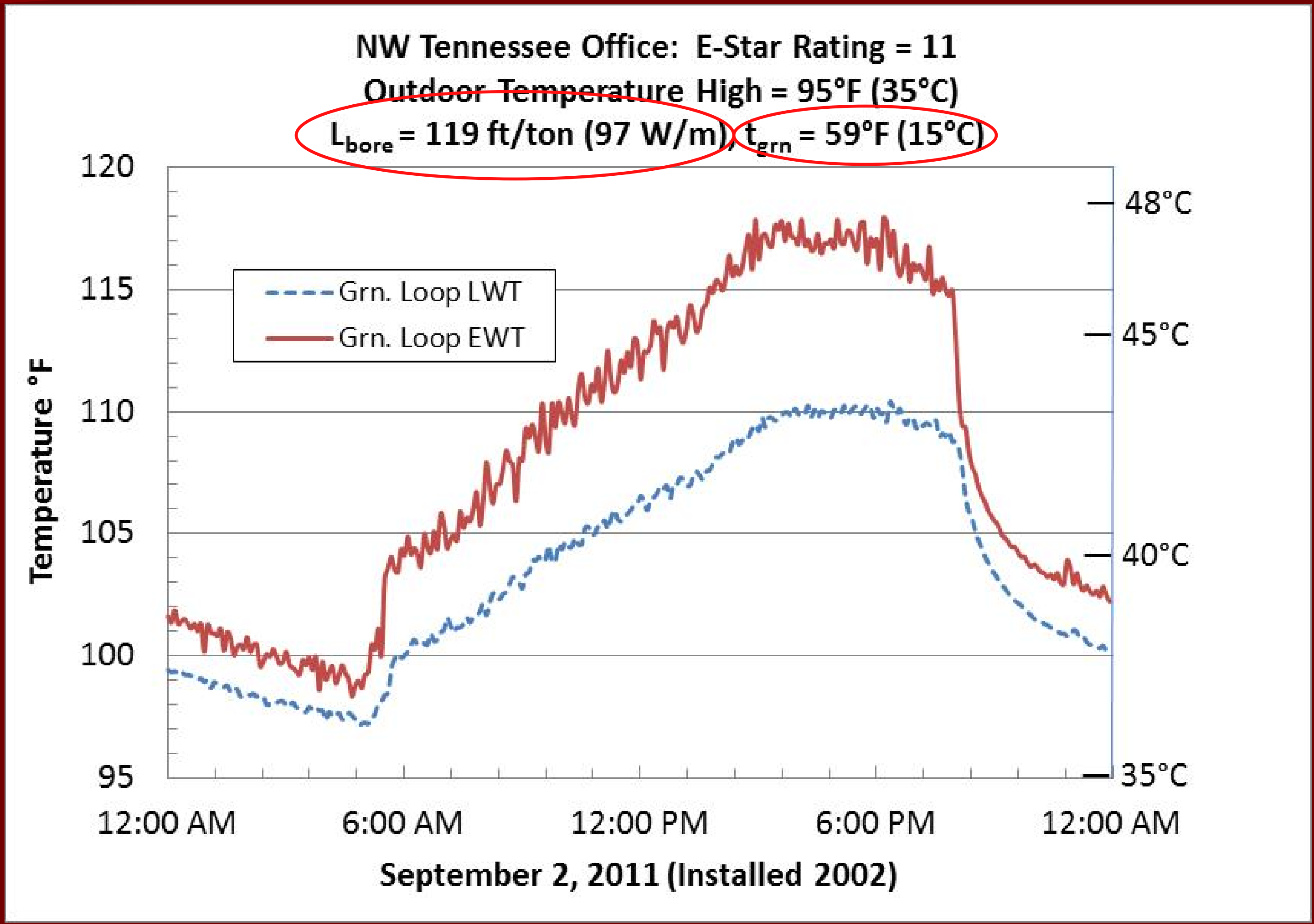




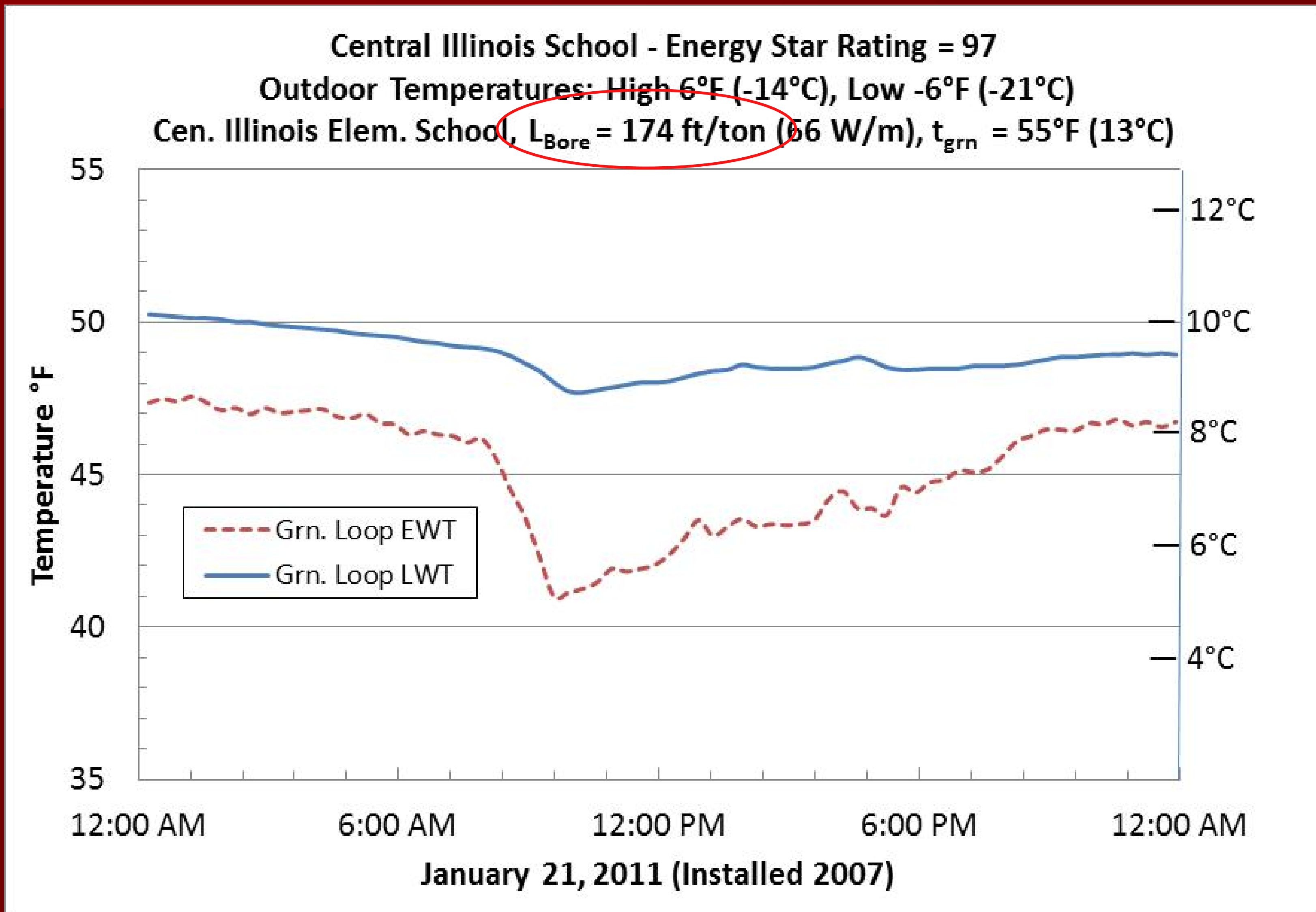
Ground Loop Performance—Nice Cooling Mode Loop Temperatures in Warm Ground after 11 Years of Operation



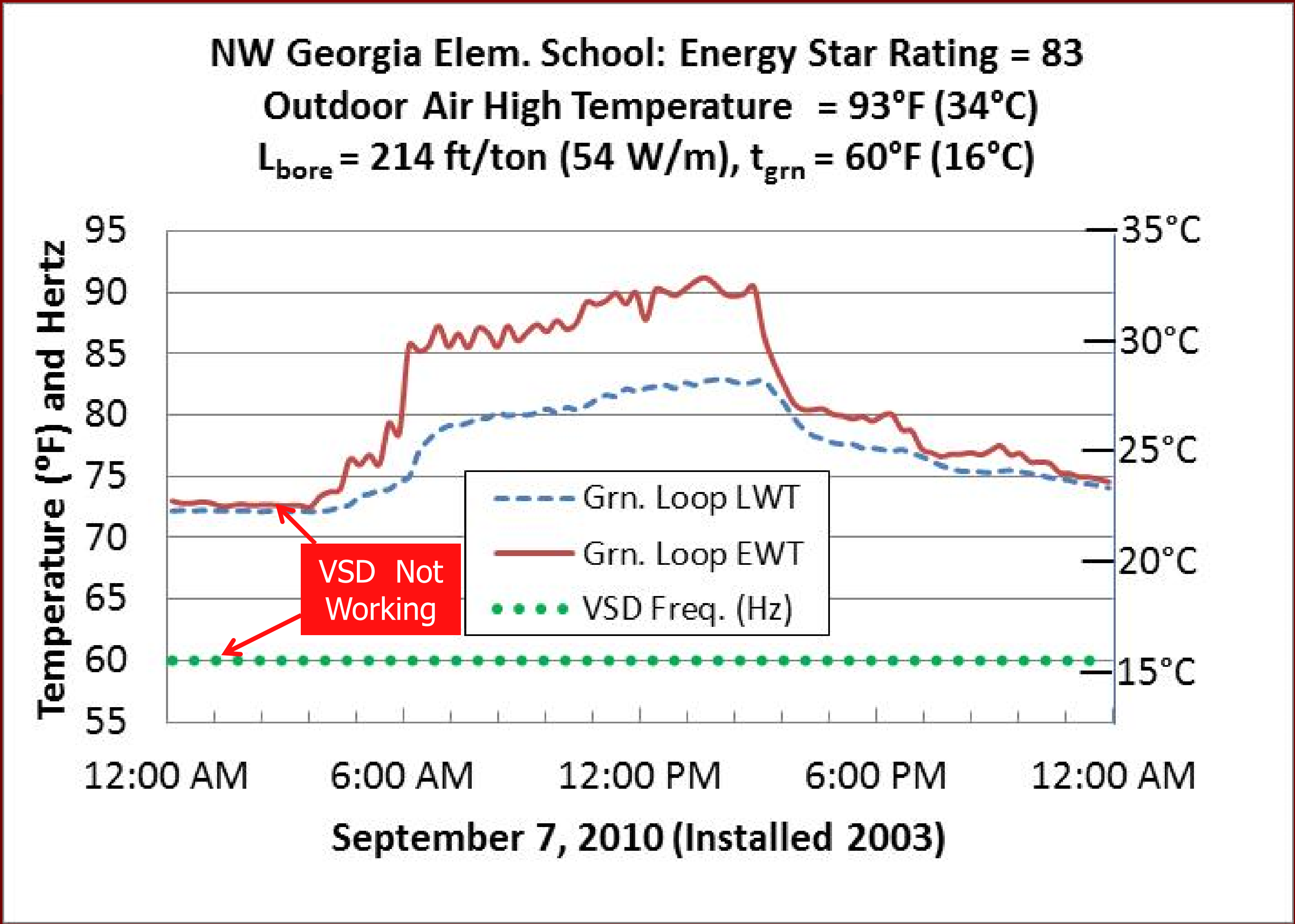
Ground Loop Performance—Hot Cooling Mode Temperatures for Short Loop GCHP after Nine Years of Operation



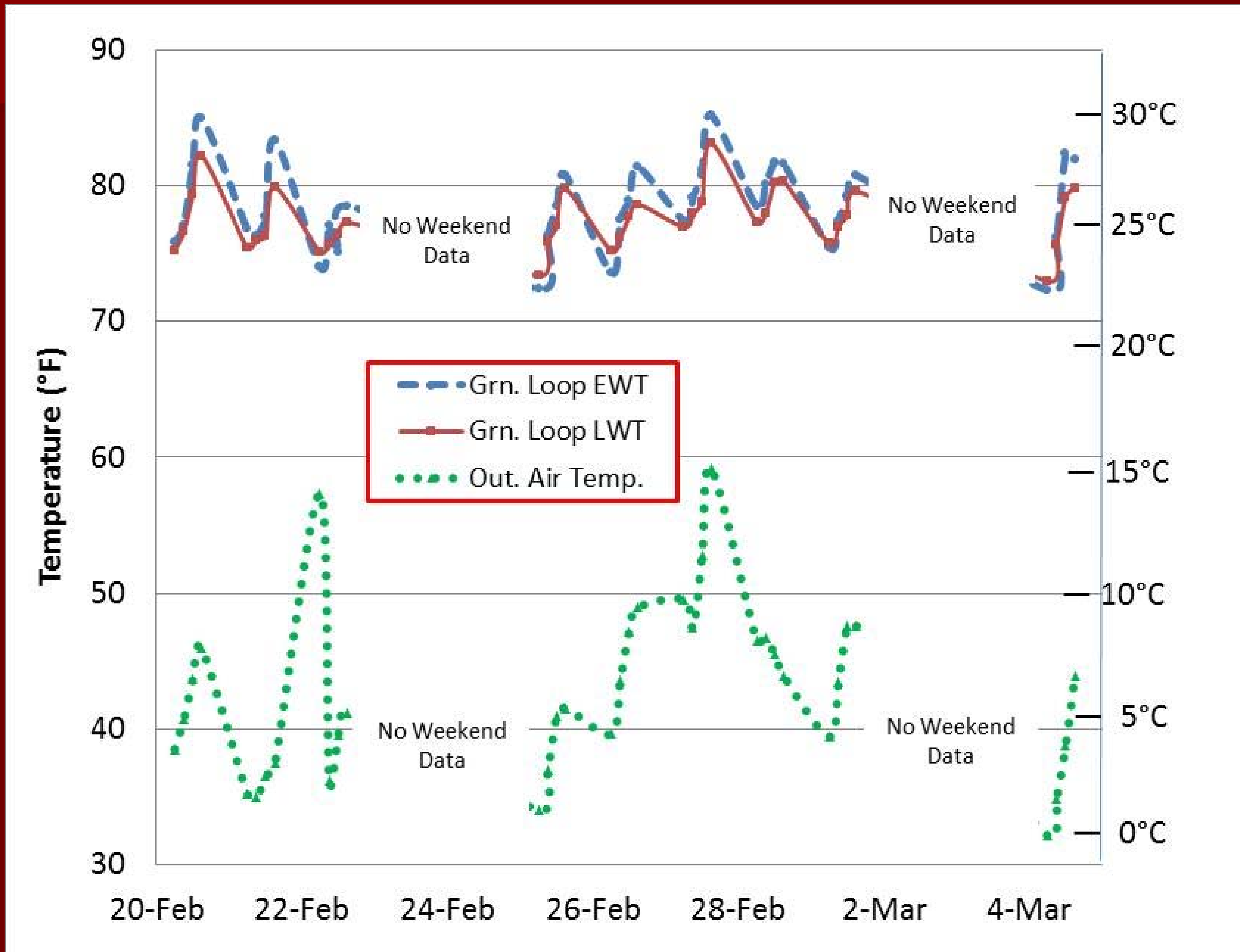
Ground Loop Performance—Nice Heating Mode Temperatures in Cold Climate



Ground Loop Performance—Cooling Mode Temperatures and VSD Speed



Why is the Ground Loop in the LEED Platinum Building Heating up in the Middle of the Winter?



Why is the Ground Loop in the LEED Platinum Building Heating up in the Middle of the Winter? (*cont.*)

- The combination of fan heat and internal loads are heating the building in the early morning
- The combination of fan heat and internal loads are overheating the building during the remaining occupied period
- In the afternoon, the heat pumps switch into net cooling to offset the fan heat and internal load
- The chilled-water pumps are also adding heat to the loop (which normally would be a good thing in the winter)

Predicting Performance of LEED Platinum GSHP Building with System Efficiency

Item		Enter Chiller Data			OR	Enter AC/HP Data						
1	Chillers or Heat Pumps	Qty.	kW/ton	Tons		Qty.	EER	kBtu/h	kW-ea.	kW-tot.	kBtu/h	tons
					---	6	14	345	24.6	147.9	2070.0	172.5
					---				0.0	0.0	0.0	0.0
					---				0.0	0.0	0.0	0.0
2a	Air Handling Unit Fans		Air Flow-cfm	TP-in wtr	η fan	η mtr.	η VSD	bhp-each	---	---	---	---
		3	17000	4	71.0%	92.0%	97.0%	15.08	12.61	37.8	-129.1	-10.8
		1	2600	4	64.0%	85.0%	97.0%	2.56	2.32	2.3	-7.9	-0.7
		1	6500	4	62.0%	88.0%	97.0%	6.60	5.77	5.8	-19.7	-1.6
2b	Fan coil or VAV Fans		Air Flow-cfm	TP-in wtr	η fan	hp-ea.	η mtr. (%)		---	---	---	---
	Enter Air Flow, TP, and							0.00	0.00	0.0	0.0	0.0
	ηfan or fan hp.							0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
3	Return Air Fans		Air Flow-cfm	TP-in wtr	η fan	η mtr.	**η VSD (%)**		---	---	---	---
		3	17000	2	65.0%	92.0%	97.0%	8.24	6.89	20.7	-70.5	-5.9
		1	2600	0.75	50.0%	80.0%	97.0%	0.61	0.59	0.6	-2.0	-0.2
								0.00	0.00	0.0	0.0	0.0
4	Chilled Water Pumps		Wtr. Flow-gpm	ΔH-ft wtr	η pump	η mtr.	**η VSD (%)**		---	---	---	---
		6	86	46	64.0%	86.0%	97.0%	1.56	1.40	8.4	-28.6	-2.4
		1	135	38	68.0%	86.0%	97.0%	1.91	1.70	1.7	-5.8	-0.5
		1	150	46	64.0%	88.0%	97.0%	2.72	2.38	2.4	-8.1	-0.7
5	Condenser Water Pumps		Wtr. Flow-gpm	ΔH-ft wtr	η pump	η mtr.	**η VSD (%)**		---	---	Click Here	
	(Ground Loop For GSHPs)	1	540	92	80.0%	91.0%	97.0%	15.68	13.25	13.3	---	---
								0.00	0.00	0.0	---	---
								0.00	0.00	0.0	---	---
6	Cond./Cooling Tower Fan	0	Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr.	η VSD	hp-each	---	---	---	---
		0	---	---	---	75.0%	100.0%		0.00	0.0	---	---
			---	---	---				0.00	0.0	---	---
			---	---	---				0.00	0.0	---	---
										kW	kBtu/h	tons
								System Totals		**240.7**	**1798**	**150**
				kW/ton =	**1.61**	**EER =**	**7.5**	**Btu/W-h**	**COP =**	**2.19**		

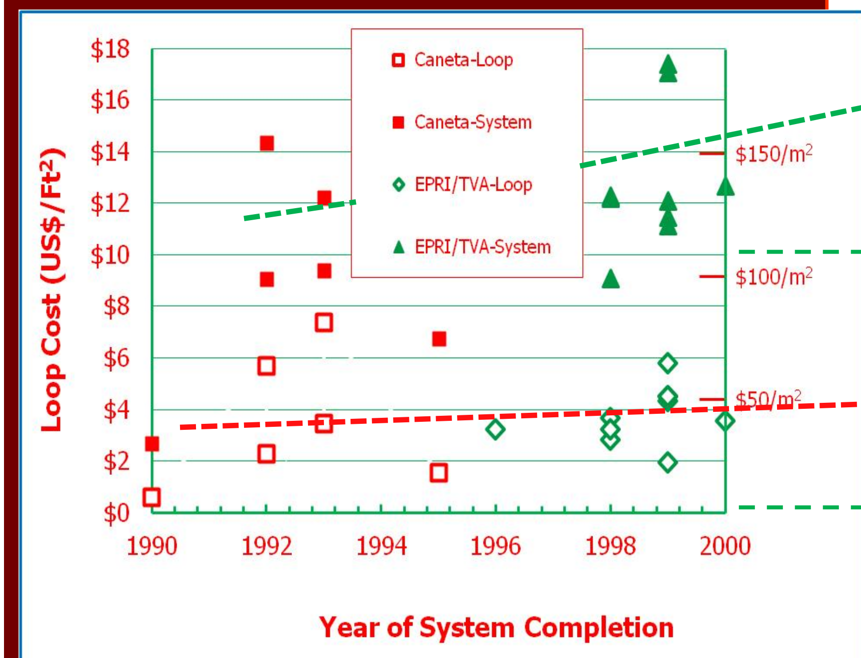
Predicting Performance via System Efficiency
Common Loop System (One of Eight)

Item		Qty.	kW/ton	Tons	OR	Qty.	EER	kBtu/h	kW-ea.	kW-tot.	kBtu/h	tons
		Enter Chiller Data			OR	Enter AC/HP Data						
1	Chillers or Heat Pumps	Qty.	kW/ton	Tons		Qty.	EER	kBtu/h	kW-ea.	kW-tot.	kBtu/h	tons
	Clg 75 EAT & 86 EWT				---	3	15.1	26.2	1.7	5.2	78.6	6.6
	ESP+Δh(filter)=0.8" wg				---	2	15.3	32	2.1	4.2	64.0	5.3
						3	15.1	37.7	2.5	7.5	113.1	9.4
					---				0.0	0.0	0.0	0.0
2a	Air Handling Unit Fans		Air Flow-cfm	TP-in wtr	η fan	η mtr.	η VSD	bhp-each	---	---	---	---
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
2b	Fan coil or VAV Fans		Air Flow-cfm	TP-in wtr	η fan	hp-ea.	η mtr. (%)	bhp-each	---	---	---	---
	Enter Air Flow, TP, and							0.00	0.00	0.0	0.0	0.0
	ηfan or fan hp.							0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
3	Return Air Fans		Air Flow-cfm	TP-in wtr	η fan	η mtr.	**η VSD (%)**	bhp-each	---	---	---	---
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
4	Chilled Water Pumps		Wtr. Flow-gpm	ΔH-ft wtr	η pump	η mtr.	**η VSD (%)**	bhp-each	---	---	---	---
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
								0.00	0.00	0.0	0.0	0.0
5	Condenser Water Pumps		Wtr. Flow-gpm	ΔH-ft wtr	η pump	η mtr.	**η VSD (%)**	bhp-each	---	---	Click Here	
	(Ground Loop For GSHPs)	3	8	28	45.0%	50.0%	100.0%	0.13	0.19	0.6	---	---
		2	9	27	45.0%	50.0%	100.0%	0.14	0.20	0.4	---	---
		3	11	25	45.0%	50.0%	100.0%	0.15	0.23	0.7	---	---
6	Cond./Cooling Tower Fan	0	Air Flow (cfm)	TP (in. wtr)	η fan (%)	η mtr.	η VSD	hp-each	---	---	---	---
		0	---	---	---				0.00	0.0	---	---
					---				0.00	0.0	---	---
					---				0.00	0.0	---	---
										kW	kBtu/h	tons
								System Totals		**18.5**	**256**	**21**
				kW/ton =	**0.87**	**EER =**	**13.8**	**Btu/W-h**	**COP =**	**4.04**		

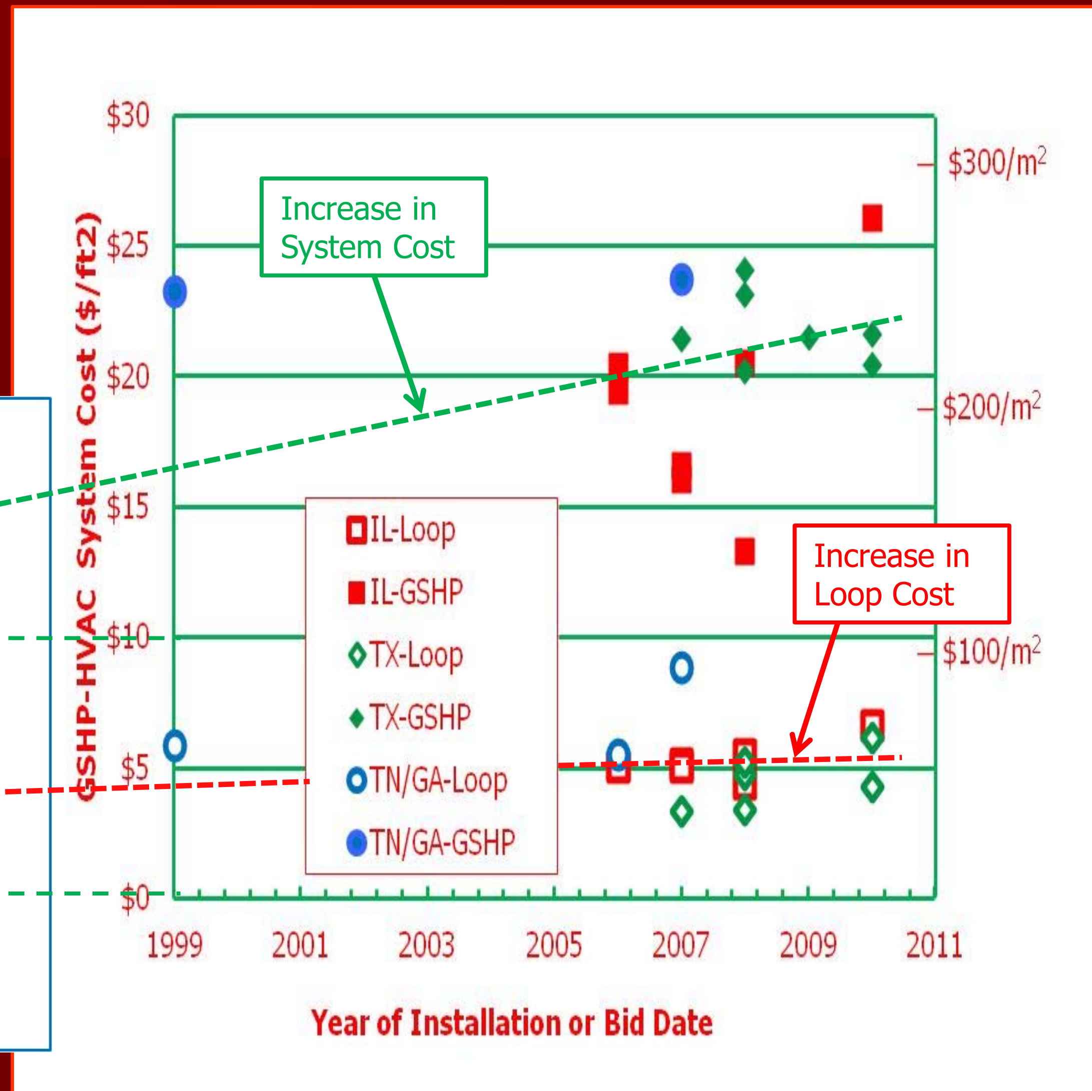
High System EER even with low efficiency circulator pumps

GSHP* Cost ($/ft²) Previous and Recent Surveys

*All systems were ground-coupled heat pumps (GCHPs)



Caneta (1995) & Zimmerman (2000).



Kavanaugh & Kavanaugh (2012).

GSHP Costs: 1995 to 2011

- The average ground heat exchanger cost in the recent survey was 26% of total GSHP cost and increased by 50% (3% per year) since 1995
- The average HVAC cost in the recent survey was 74% of the total GSHP system cost and increased by 177% (11% per year) since 1995
- Using logic (an important tool for engineering), cost optimization should include, and possibly concentrate, on the HVAC component of GSHPs

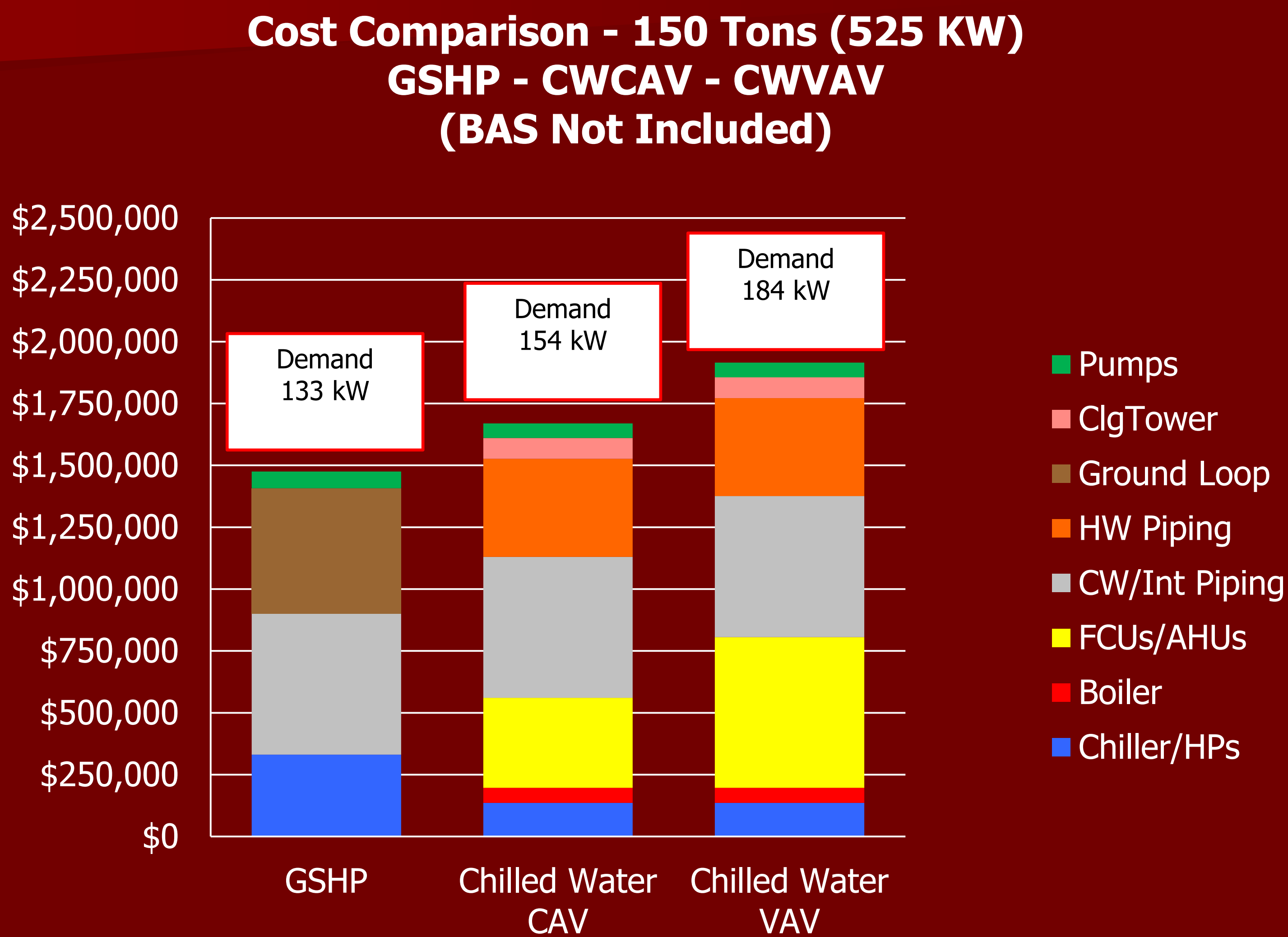
Example in GSHP Book: GSHP Equipment Cost Chilled-Water VAV Versus Common Loop Heat Pumps

Qty		Unit Cost	Total Cost
30	3-ton (11 kW) Heat pump	$3,350	$100,500
40	4-ton (14 kW) Heat pump*	$4,050	$162,000
30	5-ton (18 kW) Heat pump	$4,750	$142,500
100	1/6 hp (0.12 kW) In-line Circulator Pumps	$990	$99,000
	*Interpolated values	Total	$504,000
		Cost/ton	$1,260
		Cost/kW	$360
Option 2 - Chilled Water VAV GSHP - Two 200-ton (700 kW) Chillers - Central Loop			
Qty	Components	Unit Cost	Total Cost
2	200 ton (700 kW) WC Screw Chillers	$111,000	$222,000
8	20,000 cfm (34,000 cmh) VAV AHUs	$116,700	$933,600
40	800 cfm (1,360 cmh) FPVAV Terminals**	$5,975	$239,000
40	1200 cfm (2,040 cmh) FPVAV Terminals**	$7,400	$296,000
40	2000 cfm (3,400 cmh) FPVAV Terminals**	$11,825	$473,000
2	20 hp (15 kW) Base Mounted Pumps	$20,200	$40,400
3	10 hp (7.5 kW) Base Mounted Pumps	$16,800	$50,400
	**Deducts for no zone duct included	Total	$2,254,400
		Cost/ton	$5,636
		Cost/kW	$1,610

Vault or No Vault
400 ton (1400 kW) GCHP system with ten circuits

Qty.	Option 1 - Vault with Manifold and Valves	Unit Cost	Total Cost
1	HDPE Vault w. valves - 8" (200 mm) mains 10 -3" (80 mm) cicuits	$35,000.00	$35,000
410	8" (200 mm) HDPE DR 11 Pipe	$15.30	$6,273
2	8" (200 mm) 90° Elbows	$268.00	$536
2	8" (200 mm) Flanges	$63.00	$126
2	8" (200 mm) Pipe sleeves	$525.00	$1,050
20	3" (80 mm) Butt fusion welds	$23.50	$470
16	8" (200 mm) Butt fusion welds	$61.00	$976
			$44,431
		Cost per ton	$111.08
		Cost per kW	$31.74
Qty.	Option 2 - Ten circuits to equipment room manifold and Valves	Unit Cost	Total Cost
4100	3" (80 mm) HDPE DR 11 Pipe	$2.21	$9,061
20	8" (200 mm) HDPE DR 11 Pipe	$15.30	$306
40	3" (80 mm) Flanges	$22.50	$900
20	3" (80 mm) Pipe sleeves	$238.00	$4,760
20	3" (80 mm) Pipe saddle fitting to 8" (200 mm) main	$39.00	$780
160	3" (80 mm) Butt fusion welds	$23.50	$3,760
20	3" (80 mm) Saddle fusion welds	$70.00	$1,400
4	8" (200 mm) Butt fusion welds	$30.50	$122
2	4" (100 mm) Butt fusion welds	$23.50	$47
1	Valve set - 2-8" BFV, 20-3" (80 mm) CBV, 2-4" (100) BFV (purge)	$6,000.00	$6,000
2	8" (200 mm) Flanges	$63.00	$126
2	8" (200 mm) x 4" (100) Reducers	$109.00	$218
2	4" (100 mm) Flanges	$30.50	$61
			$27,541
		Cost per ton	$68.85
		Cost per kW	$19.67

GCHP @ $15/ft Bore Compared to Chilled-Water Systems in Alabama School*



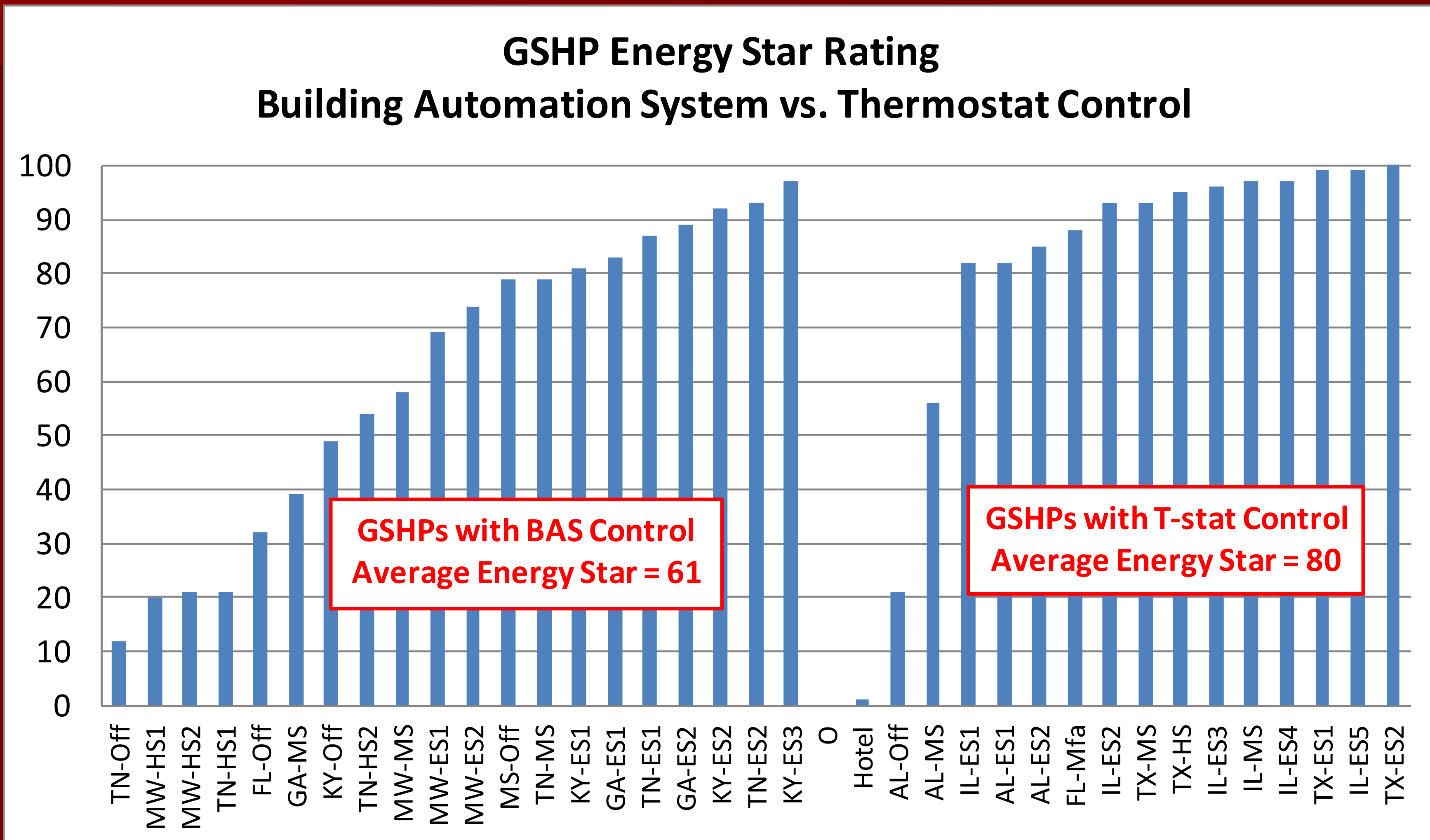
**ASHRAE Journal*, April 2016

Lower Hanging Fruit to Optimizing GSHP System Costs? Equipment and Controls*

R.S. Means 2014 Mechanical Cost Data - Controls	Bare Cost	With O&P
Sensors and Transducers	$ per Sensor	
Duct temperature sensor (with 50 ft. run in EMT)	$360	$395
Space temperature sensor (with 50 ft. run in EMT)	$575	$635
Duct humidity sensor (with 50 ft. run in EMT)	$605	$665
Space humidity sensor (with 50 ft. run in EMT)	$925	$1,025
Duct static pressure sensor (with 50 ft. run in EMT)	$490	$540
Air Flow (cfm) transducer (with 50 ft. run in EMT)	$660	$730
Water temperature sensor (with 50 ft. run in EMT, not including pipe tap)	$360	$395
Water Flow transducer (with 50 ft. run in EMT, not including pipe tap)	$2,075	$2,300
Water differential sensor (with 50 ft. run in EMT, not including pipe tap)	$850	$935
Power (kW) transducer (with 50 ft. run in EMT)	$1,175	$1,300
Energy (kWh) totalizer (with 50 ft. run in EMT, not including pulse transmitter)	$545	$600
Space static pressure sensor (with 50 ft. run in EMT)	$925	$1,025
Controllers	$ per Controller	
Multiplexer panel with function boards - 48 point	$4,575	$5,050
Multiplexer panel with function boards - 128 point	$6,300	$6,925
DDC Controller - 16 point in mechanical room	$1,925	$3,125
DDC Controller - 32 point in mechanical room	$4,725	$5,200
VAV terminal box controller with space temperature sensor	$735	$805
Front End Costs		
Computer with software program (cost vary with complexity)	$5,675	$6,250
Color graphics software (cost vary with complexity)	$3,400	$3,750
Color graphics slides (cost vary with complexity)	$426	$470
Engineering, calibration, and start-up labor (per sensor)	$292/sensor	$320/sensor
Basic maintenance manager software (cost vary with complexity)	$1,700	$1,875

*****ASHRAE *Journal*, April 2016

Factors of Influence—Method of Indoor Temperature Control



GSHP Cost Versus Performance

- Open access to cost information, both HVAC components and ground loops, is critical
- Currently, this information is limited and usually not reported, but this can change with cooperation
- ASHRAE Standard 90.1-2013 compliance is a poor predictor/indicator of ***system*** efficiency
- ENERGY STAR rating is a better indicator of ***system*** performance (for building types covered)
- System efficiency is a simple and probably better predictor of energy consumption
- Quality engineering practice can often reduce both installation and operating cost via **KISS**

Questions?

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